SNAKE RIVER SOCKEYE SALMON (ONCORHYNCHUS NERKA) HABITAT/LIMNOLOGIC RESEARCH

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PREFACE

The Shoshone-Bannock Tribes (SBT) and the Idaho Department of Fish and Game initiated Snake River sockeye salmon recovery efforts in the summer of 1991. The Tribes' have subcontracted Utah State University researchers to direct limnology investigations in potential sockeye salmon nursery lakes of the Sawtooth Valley. The objectives of our limnology work are to characterize current lake limnology conditions, relate current lake productivity levels to potential sockeye salmon(Oncorhvnchus nerkal production, and investigate ways to increase growth and survival of re-introduced sockeye salmon in the nursery lakes. The results of limnology work for spring through fall, 1992 are presented as a separate section (Part II) of this report. The Tribes conducted various investigative studies in 1992 related to fish passage, 0. nerka population dynamics, and composition of nursery lake fish communities, as well as, project oversight and management. These data and information are presented as Part I of this report. Some data have been used in both reports for continuity and context.

REPORT SECTIONS

PART I. SNAKE RIVER SOCKEYE SALMON (*Oncorhvnchus nerka*) HABITAT/LIMNOLOGIC RESEARCH.
S. Spaulding.

PART II. LIMNOLOGICAL AND FISHERIES INVESTIGATIONS OF SAWTOOTH VALLEY LAKES WITH RESPECT TO POTENTIAL REHABILITATION OF ENDANGERED SNAKE RIVER SOCKEYE SALMON.
C. Luecke and W. Wurtsbaugh.

ABSTRACT

This report outlines long-term planning and monitoring activities that occurred in 1991 and 1992 in the Stanley Basin Lakes of the upper Salmon River, Idaho for the purpose of sockeye salmon (*Oncorhvnchus nerka*) recovery. Limnological monitoring and experimental sampling protocol, designed to establish a limnological baseline and to evaluate sockeye salmon production capability of the lakes, are presented. Also presented are recommended passage improvements for current fish passage barriers/impediments on migratory routes to the lakes. We initiated *O. nerka* population evaluations for Redfish and Alturas lakes; this included population estimates of emerging kokanee fry entering each lake in the spring and adult kokanee spawning surveys in tributary streams during the fall. Gill net evaluations of Alturas, Pettit, and Stanley lakes were done in September, 1992 to assess the relative abundance of fish species among the Stanley Basin lakes. Fish population data will be used to predict sockeye salmon production potential within a lake, as well as a baseline to monitor long-term fish community changes as a result of sockeye salmon recovery activities. Also included is a paper that reviews sockeye salmon enhancement activities in British Columbia and Alaska and recommends strategies for the release of age-0 sockeye salmon that will be produced from the current captive broodstock.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

INTRODUCTION

The Shoshone-Bannock Tribes (SBT) of southeast Idaho formally involved themselves with the recovery of the Snake River sockeye salmon (Oncorhvnchus nerka) in April of 1990. In the summer of 1991, because of extremely depressed status of the Snake River sockeye stock, the Bonneville Power Administration (BPA) funded a joint recovery effort involving the Tribes, Idaho Department of Fish and Game (IDFG), and the University of Idaho (UI). Since this time (December, 1991), as a result of a SBT's petition to the National Marine Fisheries Service (NMFS), the Snake River sockeye salmon have been listed as an endangered species.

Tribal goals for Snake River Sockeye salmon include:

1. Restore, where feasible, Snake River sockeye salmon populations to historical range.

2. Conserve and protect the genetic resources represented by wild/natural Snake River sockeye salmon stock.

3. Achieve and maintain optimum utilization of existing and potential habitat for natural sockeye salmon production.

4. Manage for a minimum escapement goal to the Stanley Basin lakes of 6,000 natural/wild fish, including a Tribal and non-Tribal harvest component.

A Stanley Basin Sockeye Technical Oversight Committee (SBSTOC) was established as the working forum for oversight for BPA funded projects targeting sockeye salmon recovery. This group provides a forum for the development, coordination, and recommendation of technical alternatives for implementation. Constituent parties to the SBSTOC include: SBT, IDFG, UI, NMFS, U.S. Forest Service (USFS), the Direct Service Industries (DSI), and BPA.

This report presents information on tasks carried out by the SBT during the Fall of 1991 through October 1992. Specific task objectives include: 1) To characterize limnologic attributes for the Stanley Basin nursery lakes to assess O. nerka production limitations and production potential; 2) To develop lake potential fertilization strategies and protocol for any nursery lake(s) where lower trophic level production is currently a limitation to O. nerka survival and production; 3) Modify existing migratory blocks at outlets of Stanley Basin nursery lakes to allow for passage of sockeye salmon smolts and adults; 4) Determine O. nerka population characteristics and densities in the Stanley Basin nursery lakes; 5) Determine potential piscivorous fish effects on O. nerka populations in the Stanley Basin nursery lakes; and 6) Planning for in-lake captive broodstock production activities and management strategies in conjunction with IDFG.

Snake River Sockeye Salmon Stock Status: Past and Present

Historical stock status information on the Snake River sockeye is sparse. It has been suggested that the Snake River sockeye salmon once constituted a significant portion of Columbia River sockeye salmon production (Columbia River Fish Management Plan (CRFMP)-All Species Review, 1991). The dramatic decline of Snake River sockeye salmon occurred prior to the initiation of dam counts at Ice Harbor Dam in 1962. Snake River sockeye salmon existed in the Payette River system and in the Grande Ronde Subbasin; these populations were eliminated near the turn of the century. Activities responsible for the stock's decline and/or elimination include over-harvest, construction of hydroelectric dams and irrigation diversions in Snake River tributaries (CRFMP, 1991), and management activities that were directed toward other fish species. Currently, only a remnant population of Snake River sockeye salmon exists in Redfish Lake in the upper Salmon River area of the Stanley Basin.

Evermann (1895) during his Stanley Basin survey in 1895 observed sockeye salmon in Alturas, Pettit, Redfish, and Stanley lakes. Numerical population estimates during this time period are lacking. Sunbeam Dam (constructed in 1910 and partially breached in 1934) on the Salmon River was responsible for a near complete elimination of the upper Salmon River sockeye salmon from 1910 through the early 1940's. Mechanisms for the re-establishment of this sockeye salmon population are clearly speculative but include: 1) sockeye salmon adults, in limited numbers, were able to pass Sunbeam Dam during the dam's tenure, 2) seaward drift of kokanee individuals re-initiated an anadromous population segment, and 3) a recent history sockeye salmon residual component in the lake(s) maintained the gene pool until passage conditions became more conducive to an anadromous life history. Two hundred spawning sockeye salmon adults were enumerated in Redfish Lake in 1942 (Parkhurst 1950). Since this time sockeye salmon have returned to the Stanley Basin, primarily to Redfish Lake, with returns being extremely variable from year to year.

Bjornn et. al. (1968) presents the most complete stock assessment information for the Redfish Lake sockeye for the period of 1954-1964. Escapements of adult Redfish Lake sockeye salmon ranged from a low of 11 in 1961 to a high of 4,361 in 1955 (Figure 1). Adult sockeye salmon escapements to Redfish lake have not been intensively monitored since 1964, however, the overall productivity of the population has apparently been reduced due to continued poor population performance as observed by sockeye salmon escapements at mainstem Snake River dams (Figure 1). During the 1980's no more than 50 (1982) spawning sockeye salmon in Redfish lake were observed by Idaho Department of Fish and Game personnel (Hall-Griswold, 1990). During several years in the 1980's (1985, 1988, 1989) a few (<5) sockeye salmon adults were trapped at the Sawtooth Hatchery weir on the Salmon River, located just upstream of the confluence of Redfish Lake Creek and the Upper Salmon River (Hall-Griswold, 1990). It is not known if these fish were Alturas Lake sockeye or Redfish Lake strays.

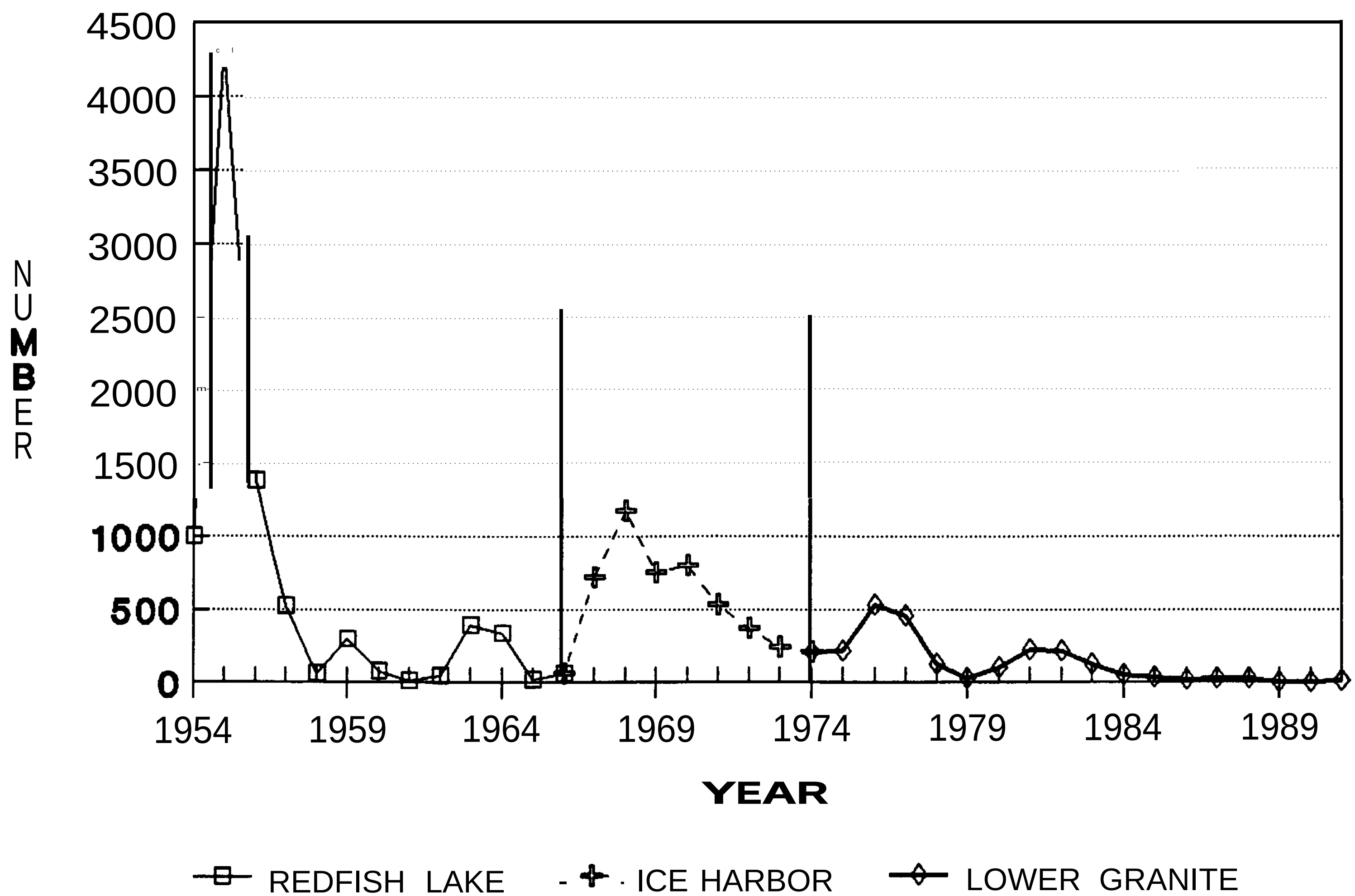


Figure 1. Snake River sockeye salmon escapements from 1954 to 1991 counted at Redfish Lake weir (1954 to 1965), Ice Harbor Dam (1966 to 1974) and Lower Granite Dam (1974 to 1991).

Currently the SBT's are involved in the recovery of the endangered Snake River sockeye salmon in a comprehensive captive broodstock/habitat enhancement effort. This work was initiated in 1991. Over 2,000 captive broodstock individuals have been brought into the program and include fish from: 1) one female and three male adults that were trapped at Redfish Lake in 1991 and spawned, 2) Redfish Lake O. nerka smolts trapped in 1991 and 1992, and 3) Alturas Lake smolts trapped leaving the lake in 1991 and 1992. Captive broodstock fish from Redfish Lake are being reared at IDFG's Eagle Hatchery and the NMFS's Montlake facility.

A portion of the fish that are currently in the captive broodstock should produce sexually mature adults in the summer/fall of 1993. By the spring of 1994, second generation fish should be ready for release back into Redfish and Alturas lakes. Potential future inclusions into the captive broodstock program include O. nerka individuals from Pettit and Stanley lakes pending genetic analysis on individuals from each population. Also, the potential presence of a resident beach spawning O. nerka group in Redfish Lake would greatly increase management and genetic opportunities for the recovery of the Snake River sockeye salmon. Given this reality, it is crucial that we gain as much information on the physical, chemical, biological, fish population and fish community dynamics as possible. In addition, planning for the release and subsequent survival assessment of captive broodstock progeny need to be established, and a long-term management plan for the Stanley Basin sockeye salmon lakes needs to be developed. This report documents our achievements towards gathering this information.

STUDY SITE

Five lakes in the Sawtooth Valley are currently the focus of the Snake River sockeye salmon rebuilding effort. The five lakes (Redfish, Alturas, Pettit, Stanley, and Yellow Belly) have either had documented observations of anadromous sockeye salmon (Redfish and Alturas lakes), or through inference from resident kokanee populations are assumed to have had previous anadromous populations (Bjornn et. al. 1968). These lakes and their outlet streams constitute a major portion of the headwaters of the Salmon River (Figure 2). Located within the Sawtooth National Recreation Area (SNRA) in south-central Idaho, most of the land in the valley is higher than 1,980 meters (6,500 feet). Lake surface areas and maximum depths range from 6.17 km^2 to 0.73 km^2 and 92 m to 26 m, respectively (Table 1).

Native fish species found in the nursery lake systems include sockeye/kokanee salmon (0. nerka), rainbow trout/steelhead (O. mvkiss), chinook salmon (O. tshawvtscha), cutthroat trout (O. clarki), bull trout (Salvelinus confluentus), sucker (Catostomus SP.)l redside shiner (Richardsonius balteatus), dace (Rhinichthvs

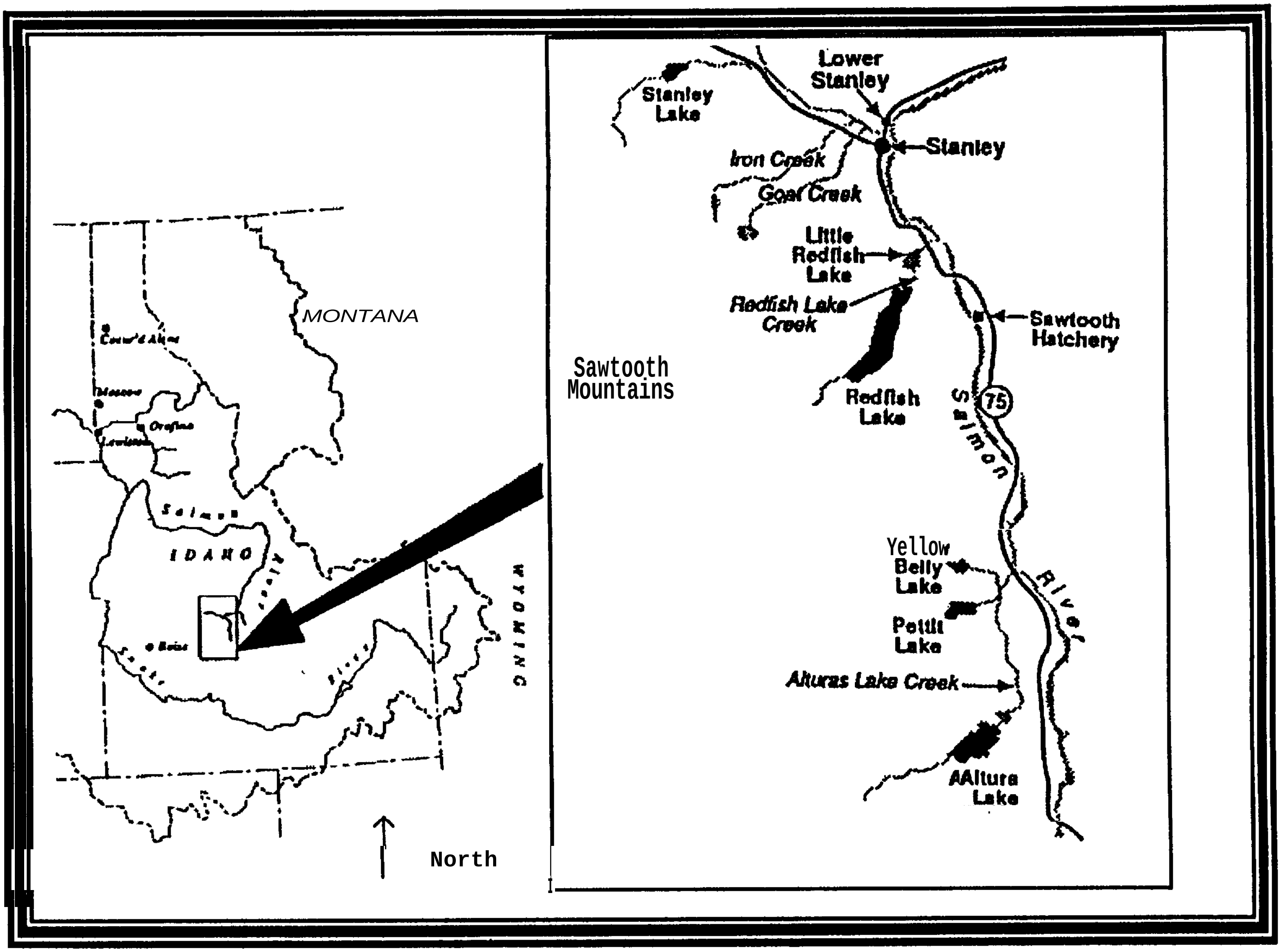


Figure 2. Location of Sawtooth Valley Lakes, Idaho.

Table 1. Morphological features of the Sawtooth Basin Lakes.

Lake	Area (km^2)	Volume ($10^6 m^3$)	Maximum Depth (m)
Redfish	6.17	251.6	92
Alturas	3.38	110.2	53
Pettit	1.63	45.1	52
Yellow Belly	0.80	10.2	26
Stanley	0.73	20.5	26

SP.), northern squawfish (Ptvchocheilus oresonensis), and sculpin (Cottus sp.). Non-native fish species include brook trout (S. fontinalis), and lake trout (S. namavcush).

METHODS

Limnoloav:

In October 1991, the Shoshone-Bannock Tribes entered into a subcontract agreement with Utah State University for the purpose of conducting limnological baseline data and research. Appendix A details work obligations under this contract and the methodologies used. Baseline parameters measured in the fall of 1992 (prior to lake turnover) and during the 1993 field season include: 1) temperature, oxygen, and light intensity profiles (1 meter intervals through the water column); 2) nutrient concentrations of filtered ortho-phosphate (FOP), total phosphorus (TP), dissolved nitrate (NO,), ammonia (NH,), and total nitrogen (TN); 3) nutrient budgets based on inflow and outflow measures throughout the year, 4) phytoplankton abundance via chlorophylla measurements by depth strata; 5) zooplankton density, biomass, and taxonomy by depth strata, and cladoceran production based on birth rates; and 6) bathymetric mapping to produce hypsographic curves by lake for the purpose of estimating lake volumes.

In addition to the baseline data collection, several in-lake nutrient bioassay experiments were done in the nursery lakes during 1992 (see Appendix A). These experiments were designed to assess whether nutrient limitation or zooplankton grazing limits phytoplankton growth at any given time during the growing season. These experiments also give an indication to the degree that phytoplankton production will be stimulated at different nutrient addition levels.

Work on a sockeye salmon growth potential model was initiated during this contract period. This model is a bioenergetic model that will allow us to predict sockeye salmon growth based on temperature and different zooplankton densities. Output from this model will give us a better indication of the current sockeye salmon production potential for each of the nursery lakes, and the potential for increased sockeye salmon production given a lake fertilization program is pursued.

Tributary Passage:

The engineering consultants J. M. Montgomery of Boise were contracted by the Shoshone-Bannock Tribes (July 1992) to conduct a detailed field evaluation of sockeye salmon passage impediments in the Sawtooth Basin. Impediment structures include three concrete rough fish barriers placed on the outlet streams of Pettit, Yellow Belly, and Stanley lakes; and an irrigation diversion on Alturas Lake Creek. We are currently working on finalizing a feasibility document that will suggest preferred alternatives for creating access to sockeye salmon access to these nursery lake systems.

0. nerka Population Characteristics:

Age-O Kokanee. In the Spring (late April) of 1992 we cooperated with the University of Idaho to estimate the number of emergent age-0 kokanee that entered both Redfish and Alturas lakes. The purpose of this work was 1) to temporally characterize this portion of kokanee life history between the two nursery lake systems, and 2) to establish an annual monitoring protocol for estimating the contribution of stream spawning kokanee salmon to the lake population of *O. nerka*. This information will be useful for establishing egg to fry survival rates, and the seasonal survival of an individual kokanee salmon year class. Additionally, this may allow us to monitor long-term kokannee inter-year population variation and also it will give us a baseline from which to measure kokanee response to sockeye salmon re-introduction.

Two steel frames (1 foot wide by 2 feet deep) connected to nylon mesh fyke nets were used to sample Fishhook Creek, an inlet tributary to Redfish Lake; and Alturas Lake Creek, an inlet tributary to Alturas Lake. Frames were anchored to the substrate using rebar. Three inch corrugated plastic sewer pipe was connected to each fyke net and traveled back to a live box. The live box (1 foot by three foot) was constructed of plywood and wire-mesh screen with a longitudinal partition used to create backwater refuge for captured fish. Each live box was situated about 30 feet downstream from the trap apparatus. For each system we established one fixed trap location. The other trap was fished randomly each night so that over the entire sampling period we would have several samples from each horizontal position across the water column.

Age-O kokanee emergence was evaluated from late April to mid June. After initial 24-hour sampling, we determined that nearly all emergence occurred during the hours of darkness. To characterize movement patterns at night, the traps were generally set at 2000 hrs and checked at midnight, 0400 hrs, and 0800 hrs. Nets were generally set every other evening through most of the sampling period; however, nets were set on consecutive evenings periodically. Mesh netting was cleaned of particulate matter using a nylon brush each time the traps were checked for fish. Fish were enumerated from the live box using an aquarium dip net. Each inlet system was fitted with a staff gage. Staff readings and water temperatures were collected nightly. At different stage levels, flow measurements were taken to allow the calculation of a flow regime throughout the sampling period.

We derived total daily emergence estimates for Fishhook Creek kokanee using a roving trap catch to fixed trap catch ratio expansion. A given stream position was fished two to four times during the emergence period by the roving trap; the ratio of our roving trap catch to fixed trap catch was expressed as the mean for these different sample days. Our daily estimate of the total number of fish moving through the water column for each sample day was the sum of all roving trap ratios multiplied by the number of fish caught in the fixed trap on that given day. To estimate the number of fish emerging on days that were not sampled we averaged the total daily estimates of fish on sampled days over a seven day period (generally four sample days). This average value was applied to non-sample days as the emergence estimate for these days.

Daily total estimates of age-0 kokanee emergence differed for Alturas Lake Creek because our roving trap was lost for several weeks due to high flows. Here we estimated total daily emergence by calculating the proportion of the water column sampled by the fixed trap, or the fixed trap and roving trap (if fished). The number of fish caught in the trap was then divided by the ratio of water sampled to account for fish in the entire water column. We feel that this calculation was suitable because of a trapping efficiency test that we ran on Fishhook Creek. Here we batch marked 350 kokannee with a bismarck brown dye and re-released fish above the traps. Our trapping efficiency was nearly identical to the proportion of water sampled, suggesting that the emerging fish were fairly uniform in their distribution throughout the water column.

Kokanee Spawner Escapement. There is a paucity of information on the dynamics of kokanee populations in Sawtooth Valley lakes. We initiated this work to follow annual trends in spawner escapements to tributary streams. This information is useful for looking at temporal spawning differences in stocks among lake systems and within a lake system by location. This information will be useful for calculating egg to emergent fry survival, and for tracking the success of the kokanee component once sockeye salmon re-introduction occurs. This work was jointly divided between the Shoshone-Bannock Tribes and the University of Idaho.

Spawning ground surveys were conducted from August 8 to September 20, 1992. Adult kokanee salmon were counted from the bank by an observer equipped with polarized sunglasses. Approximately 3.7 kilometers of Alturas Lake Creek were divided into three stream reaches (Figure 3) and counted two to three times weekly; approximately 1.7 kilometers of Fishhook Creek were divided into 7 transect areas (Figure 4) and sampled two to three times weekly. To estimate stream life for the spawning kokanee salmon we marked 25 pre-spawn adults on August 11 with florescent yarn, just below the dorsal fin. On subsequent count days the number of marked fish still living were counted. Fish totals were estimated for non-count days by dividing the difference in fish numbers between count days by the number of days between counts. This value was then added to the most recent previous count; this was done for each consecutive non-count day within that period.

Hydroacoustics. We initiated an annual pelagic fish assessment in each of the nursery lakes using hydroacoustics. This work was implemented by Utah State University after an amendment to their sub-contract. This technique allows assessment of population size of lake rearing _O. nerka_ with some resolution of age class strength, without handling the fish. This technique will be a useful monitoring tool as sockeye salmon recovery progresses and greater restrictions on fish sampling and handling are applied. In 1992 IDFG personnel trawled Redfish and Alturas Lakes, this information will be used to help calibrate hydroacoustic results. Hydroacoustic population estimates will be presented in Utah State University's annual report.

Nursery Lake Fish Community Assessment:

In 1992 we initiated a gill net evaluation of the fish communities in the Sawtooth Valley nursery lakes. Objectives of this work are: 1) to establish a standardized method for quantifying relative abundance of all fish species in each lake, and 2) to evaluate feeding habits of constituent fish species. This information will be used to assess the current potential for a predation or competition interaction between fish species in the lake and sockeye salmon. We will also be able to use fish community information in the development of an empirical sockeye salmon potential production model.

Alturas, Pettit, and Stanley lakes were sampled with variable mesh gill nets from September 14-20. Redfish Lake was not sampled because of National Marine Fisheries Service concerns relative to

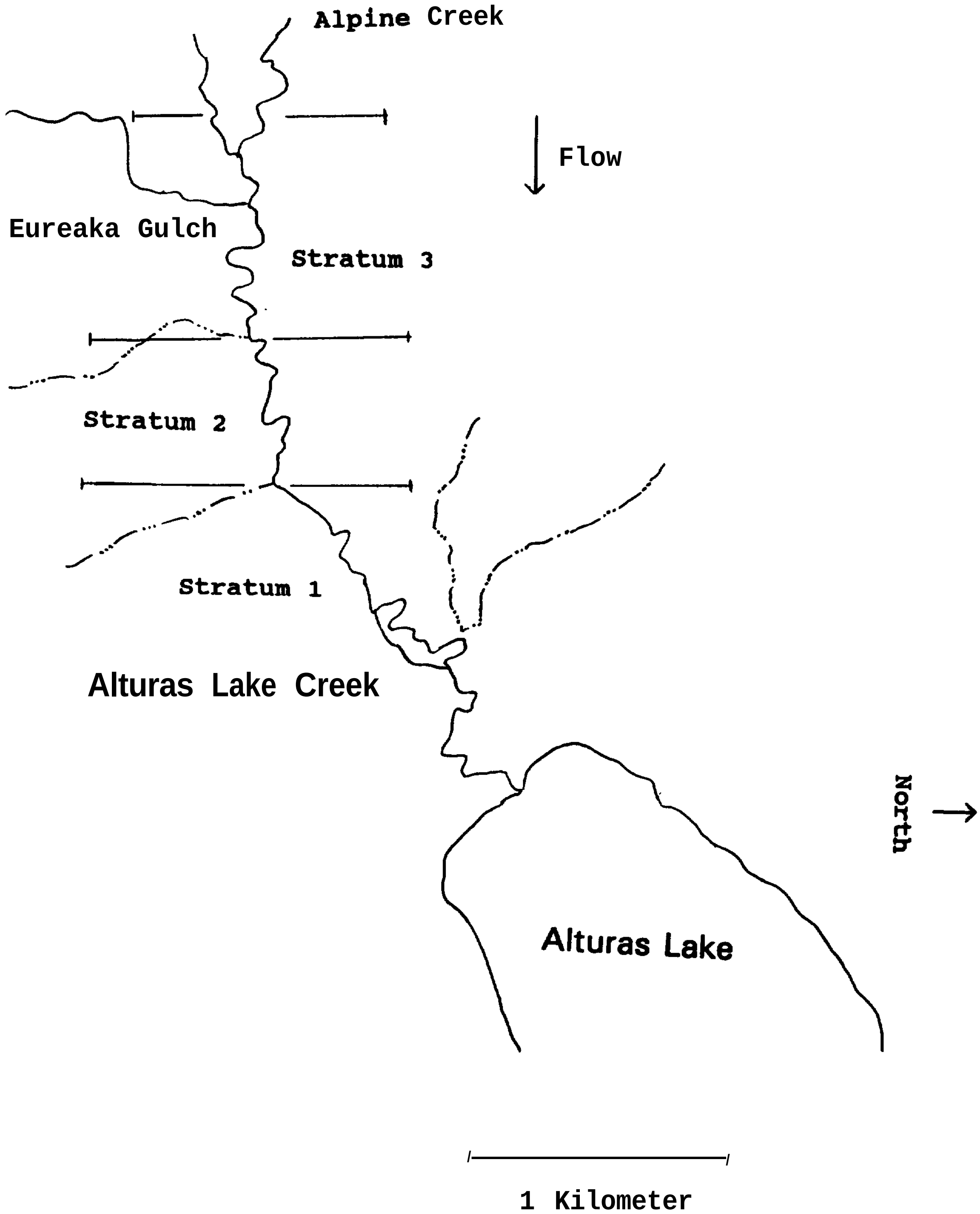


Figure 3. Kokanee salmon spawning ground survey location for Alturas Lake Creek, 1992.

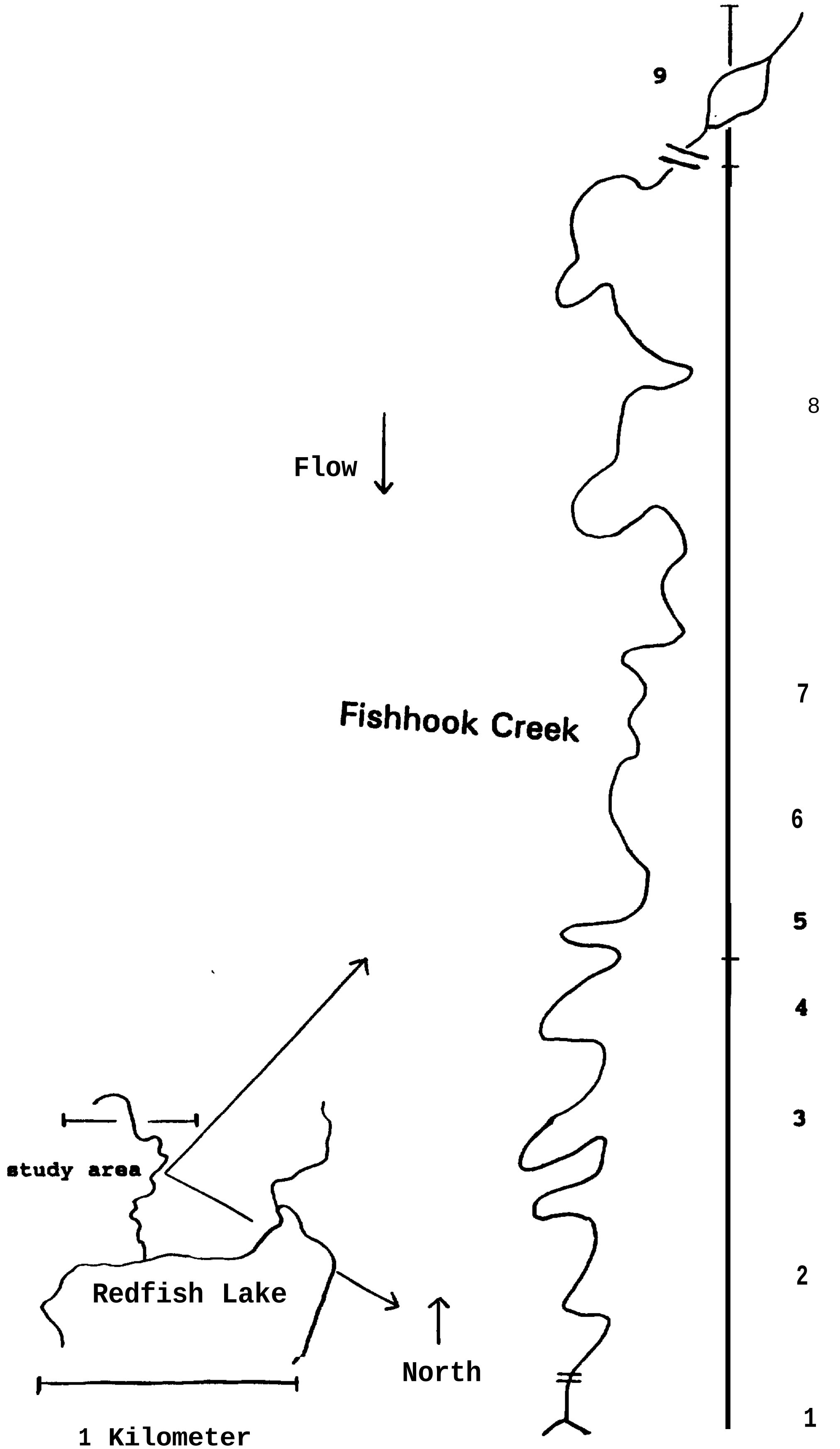


Figure 4. Kokanee salmon spawning ground survey location for Fishhook Creek, 1992.

their permitting obligation. Yellow Belly Lake was sampled by IDFG personnel earlier in June, 1992. Each gill net consisted of six 20 foot variable mesh panels; net depth was eight feet. Square measures for each panel were 0.75, 1.0, 1.25, 1.5, 2.0, and 2.5 inches. Nets were set between 1800-2000 hours and retrieved between the hours of 0700 and 1000. Eight nets were bottom set each night in two different transect areas. Each lake was sampled for two consecutive nighttime periods. Within a transect zone, different depth strata were sampled; 1) shallow: O-10 m, 2) intermediate: 11-30 m, and 3) deep: 31-40 m. Stanley Lake zones were changed to 10 m zones because of the lack of water deeper than 30 m. All net sets were bottom sets because of the tendency by many of these fish species to associate with the lake bottom at some time during the 24 hour cycle.

All fish that were caught were measured for fork length (FL) to the nearest millimeter. All mortalities were kept and sampled for gut contents; guts were removed and stored in 70% ethanol. Bull trout and lake trout were also sampled for paired fins and otoliths to determine age characteristics for the sampled fish. Lastly, tissue samples were collected from a sub-sample of all salmonid species in each lake and tested for infectious hematopoietic necrosis (IHN), and bacterial kidney disease (BKD) by IDFG personnel.

RESULTS AND DISCUSSION

During 1992 we obtained important physical, chemical, and biological data on the Sawtooth Valley nursery lakes. This information is critical to understanding the dynamics of the nursery lake systems; this will contribute to effective planning for sockeye salmon re-introduction, and subsequent monitoring and evaluation of sockeye salmon recovery.

Limnolosv:

Included as Appendix B to this report is Limnolosical Analysis of Sawtooth Vallev Lakes, Idaho, With Respect to Potential Rehabilitation of Sockeye Salmon, Preliminarv Report. This report details results of limnology work done in the fall of 1991. The more detailed seasonal limnological report for 1992 is Part II of this document. Preliminary results indicate that all five Sawtooth Valley nursery lakes are oligotrophic systems that are primarily nitrogen limited and secondarily phosphorus limited (Luecke and Wurtsbaugh; personal communication). Nutrient additions will likely enhance sockeye salmon production in each lake. The extent of sockeye salmon production benefit will be lake specific because of substantial inter-lake differences in current zooplankton densities, dissolved oxygen regimes, and piscivorous and O. nerka fish populations. In 1993 we will implement more extensive, large scale, lake fertilization experiments. These experiments,in conjunction with empirical and bioenergetic modelling of sockeye salmon production potential, will give us a sound basis for predicting eventual sockeye salmon production in these lakes relative to existing and nutrient enhanced conditions.

Tributary Passage:

We are near completion of a feasibility study that details options for improving fish passage to the nursery lakes of the Sawtooth Valley (Montgomery, 1992). Current passage impediments include concrete fish barriers that span the outlet streams of Pettit, Stanley, and Yellow Belly lakes. These barriers have been in place since the 1950's and the 1960's and they preclude any upstream passage of sockeye salmon into these nursery lake systems; eliminating roughly 50% by surface area of the Sawtooth Valley nursery lake habitat historically available to sockeye salmon habitat. Alturas Lake creek, above the Pettit Lake Creek confluence, has had an irrigation diversion in place since the early part of this century. This structure has created a migratory impediment for sockeye salmon as a result of water withdrawal and a crossbeam diversion structure not adequately designed for fish passage.

The system specific features of each fish barrier dictate different preferred solutions for creating effective fish passage. Because of the need to monitor sockeye salmon survival in each lake, through the mainstem migratory corridor, and back to the nursery lakes as returning adults, an important design criteria for passage solution is the ability to capture outmigrating smolts and returning adults for interrogation.

Stanley Lake. We recommend that the Stanley Lake Creek barrier structure not be removed, but that it be modified to accommodate fish passage and enumeration. The Potential impacts of barrier structure removal to the wetland area (approx 10.5 acres) upstream of the barrier would be significant and costly to mitigate. Montgomery recommends using a linear weir and pool fishway with a terminal holding trap (Montgomery, 1992). This structure would allow the existing wetland to be maintained, it would also allow returning sockeye salmon to pass over the concrete barrier and to be enumerated and interrogated for a PIT tag prior to being released into the lake. The remedy for smolt passage calls for either a downstream sill to allow for a landing pool below the concrete barrier for smolts, or for a downstream ramp to match the buttress slope of the barrier so that smolts will be ramped down the five foot drop. Smolt enumeration and tagging will initially be handled through the use of a screw trap. This trap will either be located near the mouth of the lake or downstream near the Stanley Lake Creek's confluence with Valley creek (Montgomery, 1992). The downstream location would offer better access during the spring.

Pettit Lake. Because of a limited existing wetland (approx 0.6 acres) above this weir and low base flow during the adult migration period, J.M. Montgomery recommends that this barrier be removed.

A trapping facility will be located just upstream of the existing barrier. The recommendation for this structure is a diagonal concrete slab supporting a picket fence barrier built in slabs which would direct fish to a trap and holding pen (Montgomery, 1992). Smolts would be collected for enumeration with a rotary screw trap fished at the adult trapping facility location just downstream of the lake outlet. These two trapping and enumeration scenarios will offer the greatest amount of management adaptability and flexibility as the sockeye program evolves. One additional option still being considered is using an adult and smolt trapping structure similar to the one constructed by IDFG at Redfish Lake. Channel morphology constraints at the current proposed trapping site may render this scheme not practical for spring time/high flow operation.

Yellow Belly Lake. The concrete barrier on the Yellow Belly Lake outlet is similar to the barriers located on Stanley Lake and Pettit Lake with little impounded wetland. Approximately one quarter mile below this barrier is an 800 m section of stream that flows sub-surface through the pore spaces of a rockfall boulder field during low flow periods.

This rockfall formation is a relatively unique geologic feature resulting from erosion of Yellow Belly Lake Creek through the glacial moraine which historically dammed Yellow Belly Lake (Montgomery, 1992). The unique features of this formation include the large size of the boulders in the creek and the absence of smaller size fraction sediments. The boulder materials in the formation are too large to have been transported by the existing hydrologic system (Montgomery, 1992). It is assumed that historic glacial action transported the boulders laterally to their present locations, and the erosive action of the stream removed the finer-grained matrix of the moraine, leaving behind the present boulder field (Montgomery, 1992). Montgomery (1992) indicates that this rockfall reach of stream has not changed significantly since the last glaciation.

The rockfall area of Yellow Belly Lake Creek would necessitate the implementation of a small scale trap and haul operation. This is not recommended at this time because of cost and because of the inherent unreliability of trap and haul programs over the long term (see Montgomery feasibility study). Because of the many unknowns still pending with the captive broodstock program, and the relatively small sockeye salmon production potential of this system, recovery implementation in Yellow Belly Lake should be low priority. As such, we recommend the concrete fish barrier be left in place until that time when fisheries managers project that this system will be needed to ensure recovery of the Snake River sockeye salmon.

Alturas Lake Creek. An irrigation diversion on this creek creates an adult salmon passage barrier when the diversion is operating in the spring and summer months (Montgomery 1982). The Forest Service through BPA funding acquired most of the water rights associated with this point of diversion through the purchase of private land within the Sawtooth Valley. The water rights now owned by the Forest Service are intended to remain in the stream to provide in-stream flows for anadromous fish. The remaining private water rights belong to L.L. Breckenridge and total approximately 6.34 cfs (Andrews, 1992). The Forest Service is presently negotiating with L.L. Breckenridge to move the point of diversion upstream and improve the efficiency of irrigation water conveyance. Under this scenario the Forest Service would completely remove the existing diversion structure to improve fish passage and maintain in-stream flows.

Given that the point of diversion is moved upstream, our strategy for adult and smolt capture and enumeration would be similar to that proposed for Pettit Lake. This includes using a picket weir for trapping adults and a rotary screw trap for trapping smolts. This trap site would be located on Alturas Lake Creek just upstream of the Pettit Lake road and upstream of the confluence of Pettit Lake Creek with Alturas Lake Creek. If the current point of diversion is maintained then the adult trapping facility would be located at this diversion using a weir and pool trap structure (Montgomery, 1992). This option is less desirable as it would require a considerable upgrade to the existing structure in addition to the ladder and trap modifications. Smolts would still be sampled using a rotary screw trap at the Pettit Lake road site.

Implementation of barrier modifications should be prioritized according to target dates for sockeye salmon re-introduction into a given lake system. Initially, given the current captive broodstock status (Redfish progeny to Redfish and Alturas Lake progeny back into Alturas Lake), a passage and enumeration solution should first be addressed for Alturas Lake. This should be completed prior to the spring of 1995. For Pettit and Stanley lakes passage remediation should be in place during the same year that fry are outplanted into these systems.

0. nerka Population Characteristics:

There are currently few data available on O. nerka population characteristics in the Sawtooth Valley lakes. Information related to year class strength of kokanee populations, and year class survival have relevance to sockeye salmon production. Potential competitive interactions may limit sockeye salmon production once re-introduction begins. Also, lake rearing densities of the overall O. nerka component will influence the interaction between an anadromous and resident form of behavior. Finally, this information is useful baseline data for comparing population responses relative to sockeye salmon re-introduction and lake nutrient increases via lake fertilization.

Population level and characteristic (ie., size structure) of O. nerka can be used to empirically classify lake systems. In Alaska recruitment limited lakes generally produce large smolts (> 60-65 mm; > 2 g) that are predominately age 1; conversely, rearing limited systems generally produce age 1 smolts near a minimum threshold size (60 mm, 2 g), or older and larger smolts as a result of extended freshwater rearing (Koenings and Burkett, 1987). Smolt production levels and mean size (> 60 mm) for Alturas and Redfish lake fish for 1991 and 1992 (Idaho Department of Fish and Game, unpublished data) suggest that smolt production is currently recruitment limited. As sockeye salmon re-introduction proceeds we will be able to empirically determine smolt production limitations (e.g., fry/forage base ratio, growing season, and temperature regime), smolt production capacity, and lake fertilization utility.

Age-O kokanee-Fishhook Creek. Age-O kokanee salmon emigrated from Fishhook Creek into Redfish Lake from April 21 through June 12, 1992 (Figure 5). Peak daily emergence was on the May 19, estimated at 4,701 fish. The population estimate for this period was 35,545 fry. Water temperature during the kokanee emergence period ranged from 4 C to 12 C. This population was the product of a 1991 estimate of 7,200 adult kokanee spawners (Brannon, 1992). Data on sex ratio for these spawners is unknown. Assuming a 1:l ratio of male to female kokanee spawners in 1991, the estimated egg deposition for 1991 was 1,080,000 assuming approximately 300 eggs per female (personal communication, Dr. Ernie Brannon, UI). From this, the calculated kokanee egg to emergent fry survival estimate is 3.3%. This value compares similarly a range of kokanee egg to fry survival values (1% to 4%) cited by Rieman (1992) for several north Idaho lakes.

IDFG trawled Redfish Lake for rearing _O. nerka_ in September, 1992. These data have not been summarized to date. This information will allow us to estimate fry to parr survival for this year class during the summer rearing period in 1992. This information, however, may be confounded by the fact that in-lake _O. nerka_ spawning may have occurred in the fall of 1991. Redfish Lake's other inlet tributary, Redfish Lake Creek, has limited spawning habitat and is thought to support little, if any, kokanee production. No spawning kokanee salmon were sighted during a cursory spawning ground survey of this creek in August and September of 1992.

Utah State University used hydroacoustics to conduct a population estimate of the pelagic fish community on September 23, 1992. This method yielded a population estimate of 107,784 fish in the 30-70 mm size range. This value is considerably larger than our spring 1992 emergent kokanee fry population estimate of 35,545 fish. This information is currently being refined and will be calibrated with IDFG's trawl information. The hydroacoustic method is unable to discern species and the possibility exists that pelagic shiners were included in Utah State's population estimate.

Age-O Kokanee-Alturas Lake Creek. In Alturas Lake Creek we observed emergent age-0 kokanee from May 16 to June 22, 1992 (Figure 6). The estimated emerging stream population for Alturas

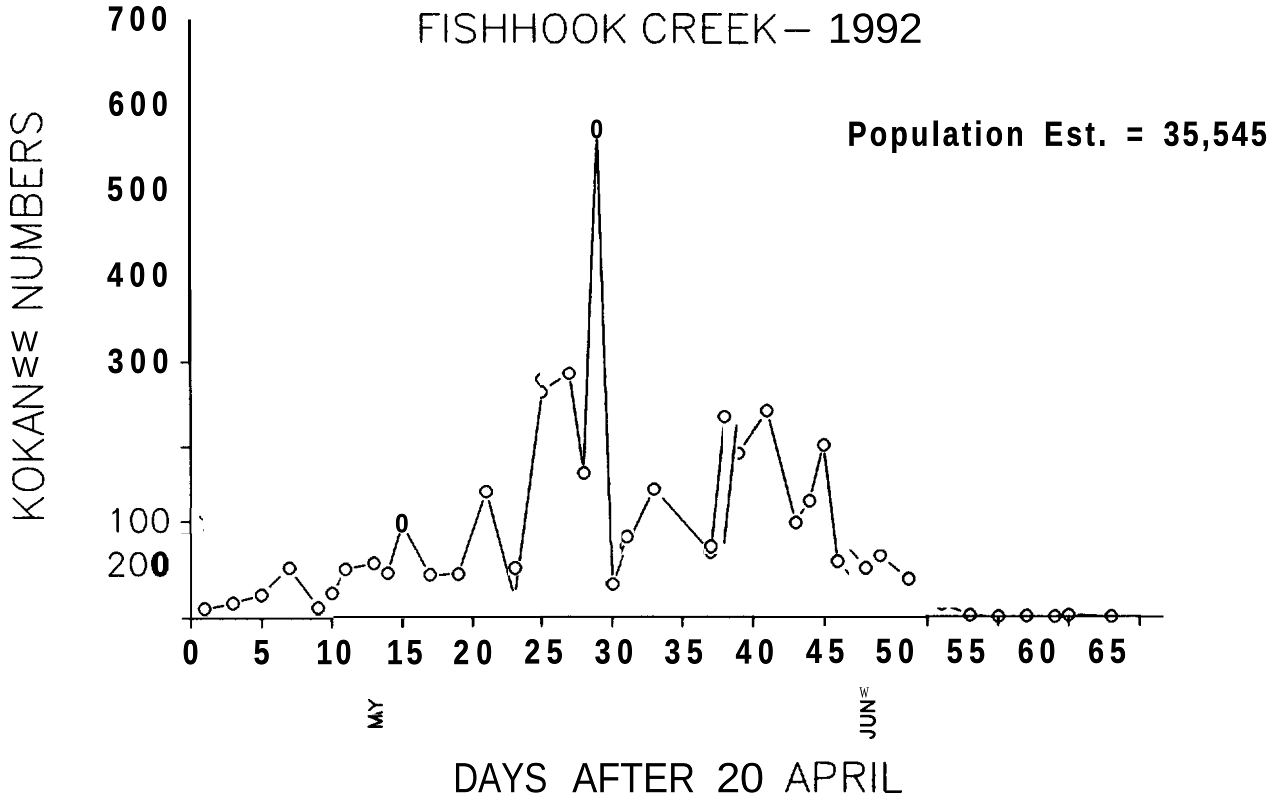


Figure 5. Counts of Fishhook Creek age-0 kokanee salmon emerging and emigrating into Redfish Lake from April 21 to June 12, 1992.

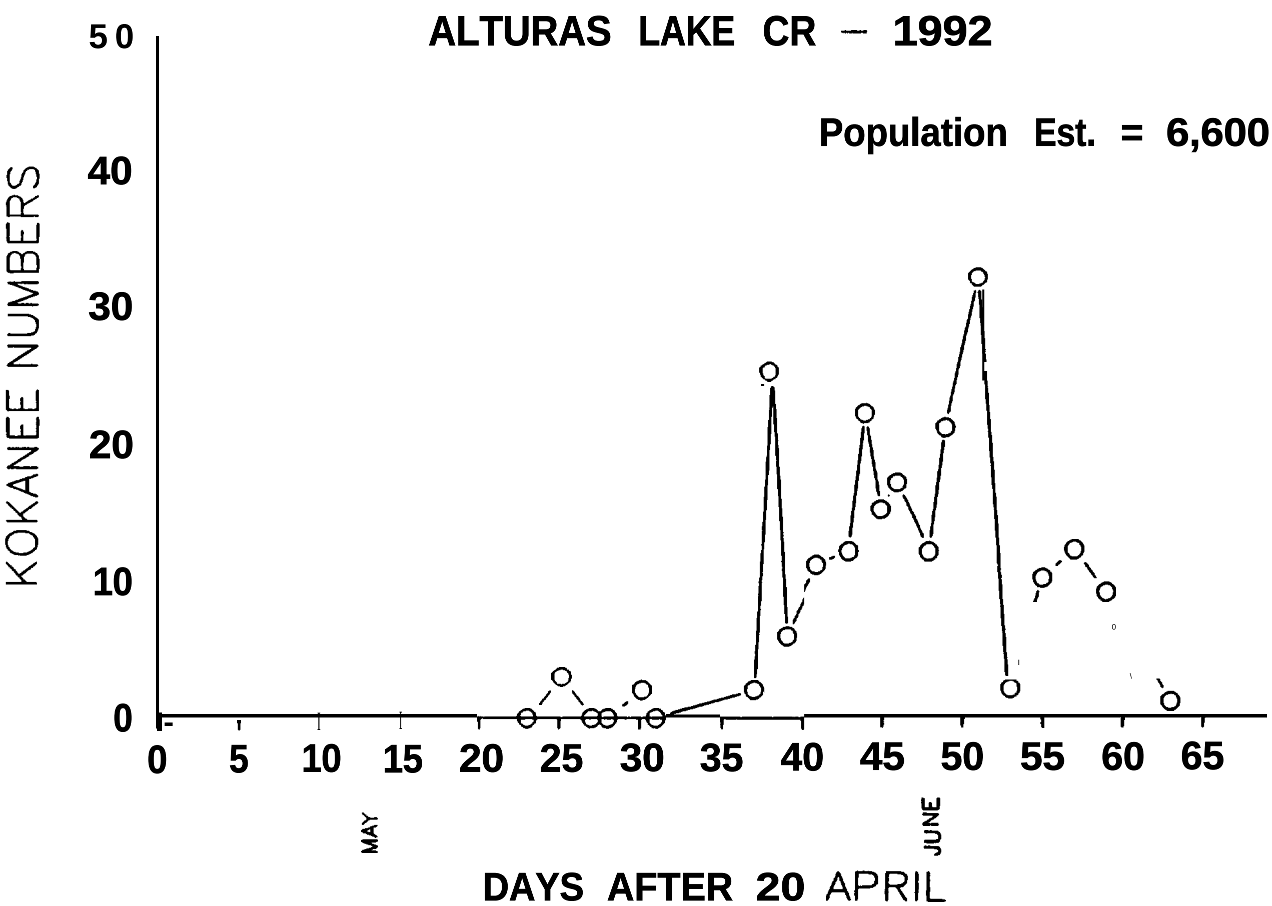


Figure 6. Counts of Alturas Lake Creek age-0 kokanee salmon emerging and emigrating into Alturas Lake from May 16 to June 22, 1992.

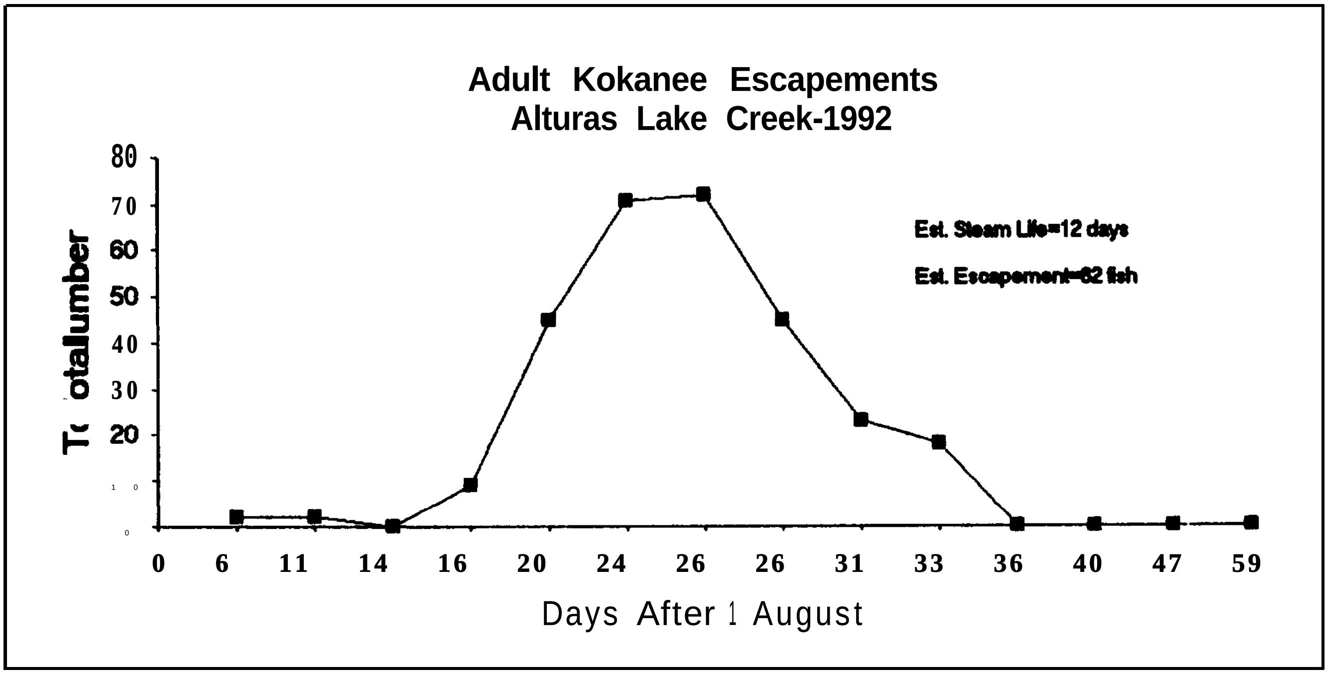
Lake Creek in 1992 is 6,600 fish, with a peak daily estimate of 591 fish on June 10. Peak kokanee emergence appeared to be approximately one week later than that for kokanee Fishhook Creek (Figures 5 and 6). This may be partially explained by either colder mean water temperatures through the incubation and hatch period, or a later fall spawning time. Water temperatures during the sampling period ranged from 2°C to 10°C. This was, on average, 2°C cooler than spring water temperatures in Fishhook Creek.

In 1991, Idaho Fish and Game personnel did a cursory spawning ground survey on August 26. Only two spawning kokanee were observed near the lake below a beaver dam (Bruce Rieman, IDFG Memorandum). Our 1992 spawning ground survey from August through September suggests that the peak spawning period was missed in 1991. However, from our age-0 kokanee population estimate it is obvious that the kokanee spawner escapement in 1991 that produced the 1992 age-0 kokanee stream population was small.

Utah State University's hydroacoustic population estimate for Alturas Lake pelagic fish (30-70 mm) during September was 51,804. Similar to Redfish lake, this population estimate is considerably larger than our population estimate (6,600) for recruited age-0 kokanee salmon for 1992. Again, this may be the result of undocumented kokanee salmon recruitment from a lake spawning population segment. This was indicated during our September gill net effort in Alturas Lake. We caught one gravid kokanee female along the south shore. After this time, we did not see any more kokanee spawners using the inlet stream. Investigation is needed to document lake spawning populations of kokanee salmon to grasp a greater understanding of the _O. nerka_ population dynamics in all of the Sawtooth Valley nursery lakes.

Xokanee Spawners-Fishhook Creek. Based on an estimated stream life of 12 days for kokanee salmon spawners we estimated a spawner population of 9,606 fish in Fishhook Creek (Figure 7; Appendix D). Spawning started in the first week of August and was monitored through September 17 when most fish were post-spawners. Spawner distribution within the surveyed section of stream varied over time (Appendix D). The early population segment (8/6 to 8/21) generally used the upper areas of the study reach (transects 5-8), while the later population segment (8/24 to 9/17) used the lower transects (l-4) to a greater extent. The 1992 kokanee spawner escapement was similar to that estimated (7,200 fish) during the fall of 1991 (Brannon, 1992). In 1993 we could expect a similar recruitment of age-0 kokanee into Redfish Lake from Fishhook Creek based on our estimated kokanee spawner escapement for 1992.

Xokanee Spawners-Alturas Lake Creek. We observed very few adult kokanee spawners in Alturas Lake Creek from August 6, 1992 through September 28, 1992 (Figure 7; Appendix D). We estimated a 1992 spawning population of 62 fish. Spawning fish primarily used the gravel in the upper portion of transect 1, and to a lesser extent they used spawning areas in transect 2 (Appendix D). Spawning kokanee salmon were not observed in the upper transect of our



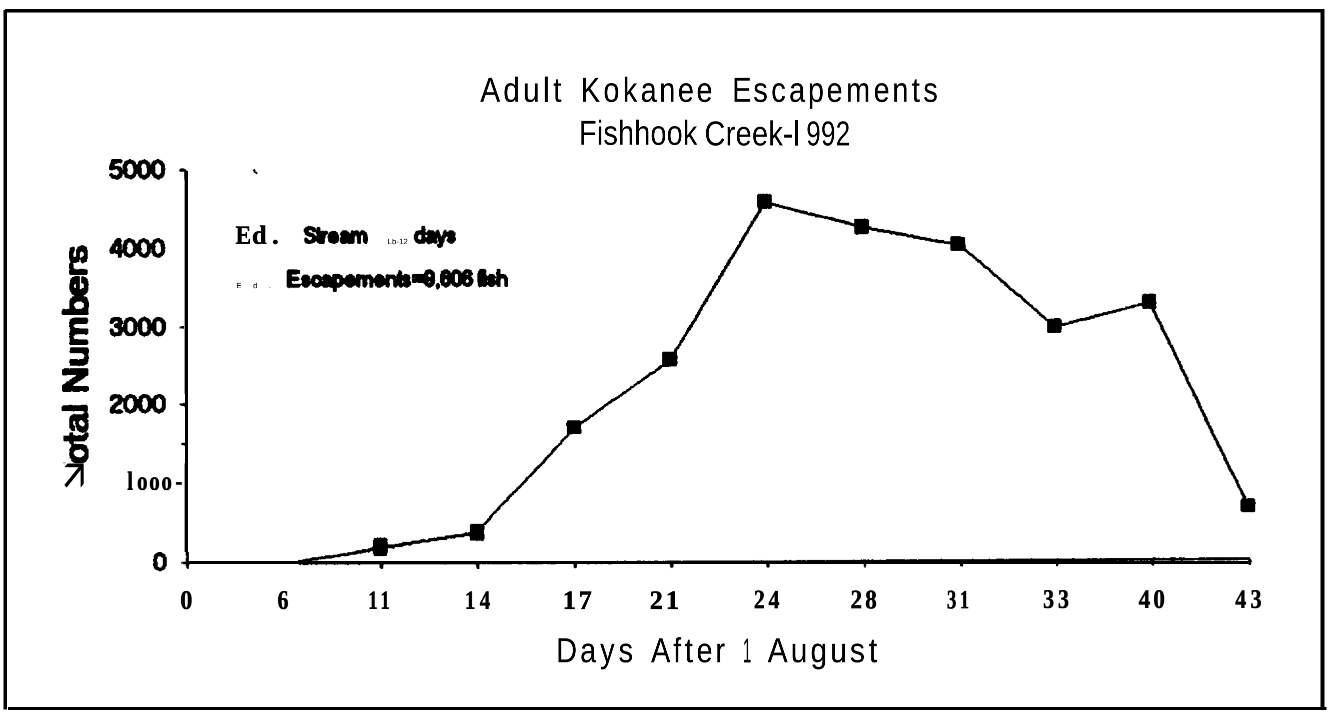


Figure 7. Adult kokanee salmon spawning ground survey counts for Fishhook Creek and Alturas Lake Creek during August through September, 1992.

survey site. We also checked the stream twice in October to insure that a late segment of kokanee spawners was not missed; we observed no fish. If Alturas Lake Creek is the only kokanee salmon production area for Alturas Lake then we should expect an extremely small age-0 year class in O. nerka in 1993.

Nurserv Lake Fish Community Assessment:

The placement of rough fish barriers on the outlet streams of Pettit, Stanley, and Yellow Belly Lakes has resulted in the formation of considerably different fish communities in these lakes compared to fish communities in Alturas and Redfish lakes, systems without barriers (Figure 8). Pettit and Stanley lake fish communities were dominated by game-fish populations of rainbow trout and brook trout; gill-net catch per unit effort ranged from 0.07 to 0.13 fish/hour. Stanley Lake also has a substantial lake trout component with a relative abundance at 0.12 fish/hour. An Idaho Fish and Game gill net effort in Yellow Belly Lake in June, 1992 suggests the fish community primarily consists of cutthroat trout and brook trout, with catch per unit efforts of 0.47 fish/hour and 0.32 fish/hour, respectively (IDFG; unpublished data).

The Alturas Lake fish community was dominated by non-game fish populations of suckers and squawfish, 0.85 fish/hour and 0.51 fish/hour, respectively; however, bull trout and rainbow trout population components were also fairly well represented (Figure 8). Gill net sampling in Redfish Lake by the Idaho Department of Fish and Game in July, 1991 suggests that the fish community in this lake is most similar to that in Alturas Lake with the three most abundant species being suckers, rainbow trout, and squawfish at 3.17 fish/hour, 0.53 fish/hour, and 0.27 fish/hour, respectively (Liter and Lukens, 1992).

Lengths of rainbow trout in Alturas, Pettit and Stanley lakes ranged from 170 mm to 350 mm, with most fish in the 200 mm to 300 mm size range (Figures 9-11). Brook trout in Pettit and Stanley lakes had similar length frequency distributions; however, lake trout in Stanley Lake were represented by fish ranging in length from 240 mm to 820 mm. Bull trout and squawfish in Alturas Lake ranged from 320 mm to 530 mm and 150 to 420 mm, respectively (Figure 90).

Foraging habits and habitat use by fish populations will help to determine the potential for interaction (competition and predation) between O. nerka and other lake populations. In 1992 we collected these data, however, they have not been quantified and summarized this information yet. This information will be useful for estimating O. nerka production potential and limitation, as well as for directing future management goals for the Sawtooth Valley nursery lakes.

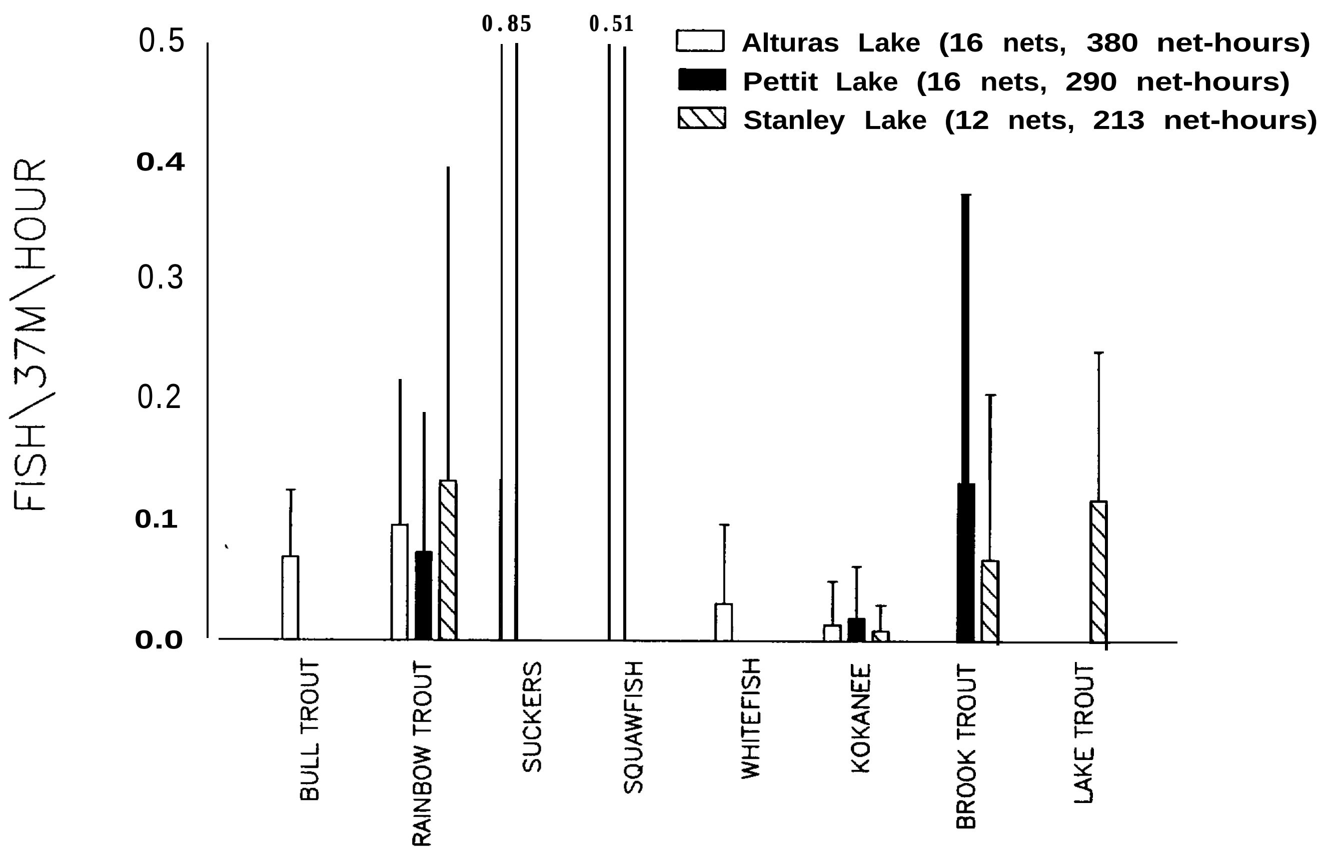


Figure 8. Relative abundance of fish populations sampled by gill net in Alturas, Pettit, and Stanley lakes, September, 1992.

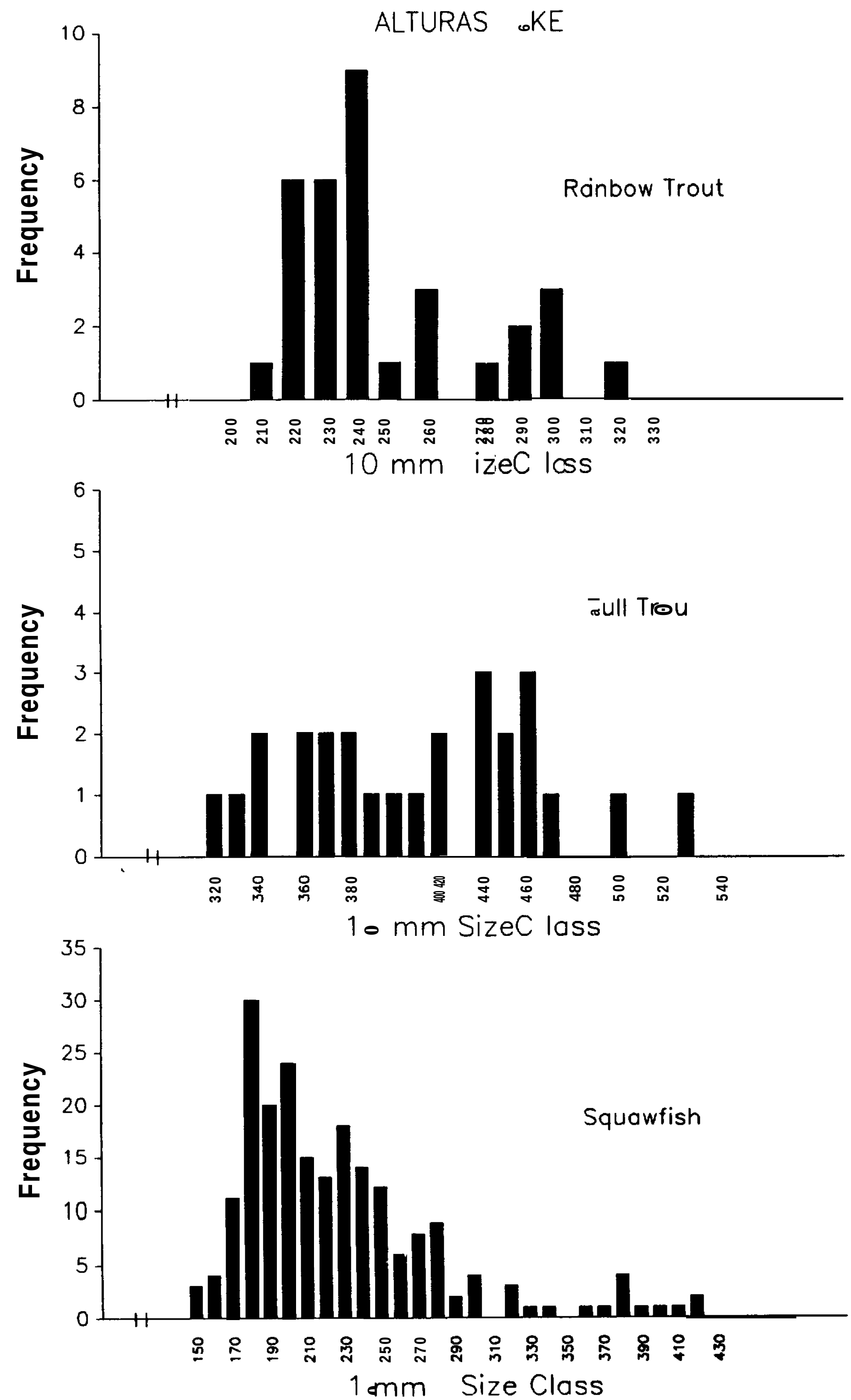


Figure 9. Length frequency distributions of rainbow trout, bull trout, and squawfish sampled in Alturas Lake, September, 1992.

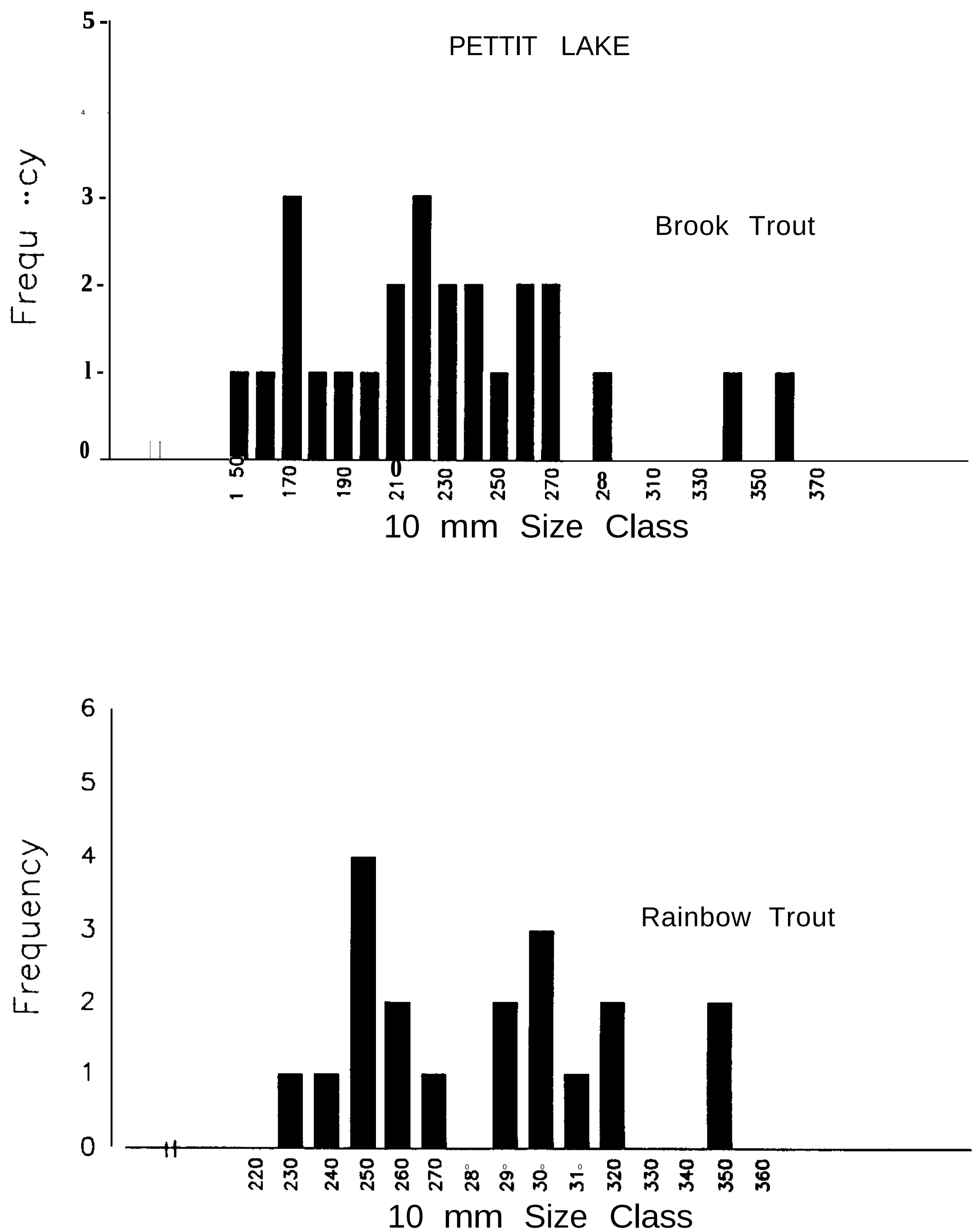


Figure 10. **Length frequency distributions of brook trout and rainbow trout sampled in Pettit Lake, September, 1992.**

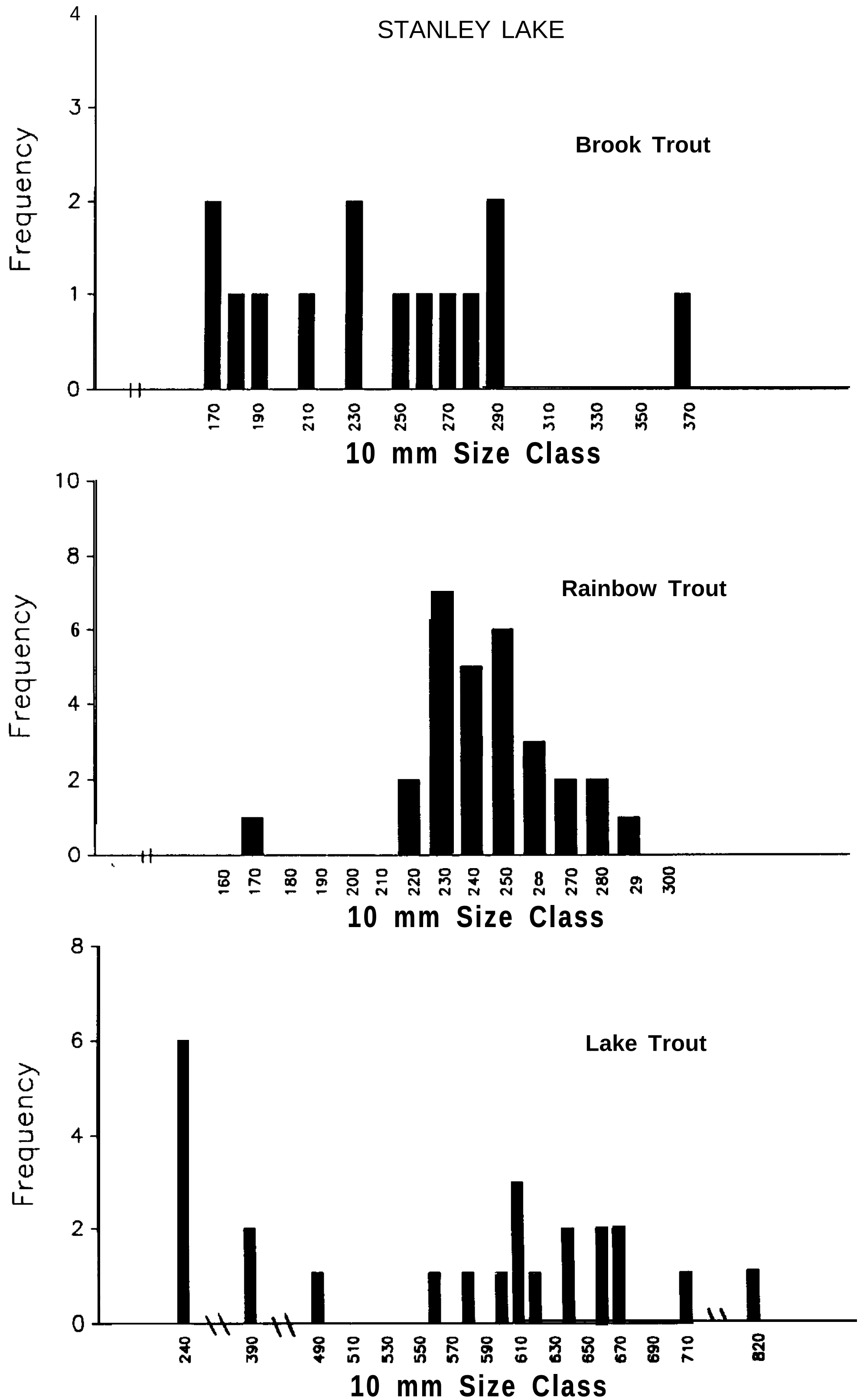


Figure 11. Length frequency distributions of brook trout, rainbow trout, and lake trout sampled in Stanley Lake, September, 1992.

Release Strateaies:

In preparation for the forthcoming captive broodstock progeny production, the Tribes developed the document: Snake River Sockeye Salmon- An Analysis of Release Stratesies. This document is included with this report as an appendix (Appendix F). We surveyed the literature for sockeye salmon production and juvenile release strategies, primarily from Alaska and British Columbia, to assess different methods and their relative merits. This exercise was done to help direct our program at the appropriate time.

We developed two recommended release strategies for the Sawtooth Valley nursery lakes. These recommendations were developed using nursery lake sockeye salmon fry or pre-smolt survival (if pertinent), smolt production, and fish survival after leaving the nursery lakes as criteria. The recommendations are: 1) Rear fish to presmolt size in the hatchery, place fish in net pens in the fall and feed for several weeks, then release fish into the lake by October to overwinter and leave the lake on their own volition in the spring, and 2) net pen rear fingerlings in the lake from 3 gm to 9.5 gm during June to October, then release these fish from the pens directly to the lake in the fall to overwinter and outmigrate in the spring. Initially it is likely that we will use some combination of these two strategies to evaluate the relative success of fish reared under both regimes.

FUTURE RESEARCH

Our 1992 research has established valuable baseline information relative to the long-term recovery goals for the Snake River sockeye salmon. In addition, this work has provided insight into future research needs.

Limnolosv

Much of the same seasonal limnology monitoring that was established and accomplished in 1992 will be continued in 1993. Several new experiments are proposed. We plan to evaluate kokanee growth rates in net cages for Redfish and Stanley lakes. Net cages will be placed at different water column strata with approximately 15 kokanee per cage to simulate different water temperature rearing regimes. Fish weights and lengths will be measured at monthly intervals from spring through fall. This information will be used as a field comparison to test the validity of a sockeye salmon growth rate model that Utah State University is developing.

Limno-corral experiments in Redfish and Pettit lakes will also be conducted. These experiments consist of 5 m diameter and 20 m deep mesocosms that are placed in the lakes with approximately 30 kokanee per corral. These closed systems will be treated with nutrient additions to stimulate chlorophyll concentrations approximately 2.5 times and 5 times ambient lake chlorophyll levels. These experiments are designed to evaluate sockeye salmon growth response to nutrient addition. Both of these experiments will be implemented by Utah State University personnel.

Fish Communities

We will continue our Alturas and Redfish Lake O. nerka work involving the age-0 emergent fry populations and the spawning ground surveys. We will expand on this work by doing summer and fall lake surveys using SCUBA in an attempt to document lake spawning population segments of O. nerka. We initiated this type of work in Redfish Lake in the fall of 1992. Here we were able to document spawning O. nerka individuals in the historic sockeye beach spawning area at a time when sockeye salmon spawn, approximately two months later than the stream spawning kokanee. Determining the relationship of these populations to the other lake O. nerka populations should have direct relevance to sockeye salmon recovery efforts.

In the Spring we will attempt to sample O. nerka smolts from both Pettit and Stanley lakes. This will done to 1) document the presence of this life history form, 2) to sample these individuals for genetic analysis, and 3) to PIT tag a sample of these individuals so that we can track the fate of these individuals through the mainstem hydro-projects. This information may help to further clarify the utility of using the endemic lake populations for sockeye salmon rebuilding in the future.

We will continue a gill net sampling protocol similar to the one used in 1992. We may also do some netting on a more seasonal basis to track resource partitioning changes throughout the summer/fall season. Utah State University will continue their hydroacoustic evaluation of the nursery lakes. This will be done in conjunction with an IDFG trawl crew to maximize the information gained relative to hydroacoustic calibration.

Finally, we will be involved in planning for the 1994 release of captive broodstock progeny back into Redfish and Alturas lakes (given successful reproduction). This will include finalizing plans for release and implementing release strategies. This may include net pen construction and in-lake captive fish rearing during part or all of the growing season.

ACKNOWLEDGEMENTS

Paul Dann of the Shoshone-Bannock Tribes was instrumental in collecting field data during the 1992 field season; also, Mike Rowe, Wes Stonecypher, Kermit Bacon, and Hal Hayball of the Tribes assisted in gill net sampling. Dr. Ernie Brannon shared freely towards the development of field sampling protocols for kokanee populations and assisted in data collection. Keya Collins of the University of Idaho constructed kokanee fry fyke nets. Drs. Chris Luecke and Wayne Wurtsbaugh, Utah State University, contributed sampling design input for fish community assessments, and Phaedra Budy of Utah State University was key to the execution of the gill net sampling.

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Exhibit A
Appendix A

Limnology Workplan

1991 Work Plan

Physical parameters and 02 **- we will measure temperature and oxygen concentrations using a YSI calibrated meter** at **l-m intervals at the central sampling station of each lake. These profiles will allow us to determine whether fall destratification is complete. If so, upper water column nutrient concentrations will be representative of the entire water column.**

Nutrient concentrations - Water samples for nutrient analysis will be collected from 10 m to the surface of each lake using an integrated tube sampler (3 cm diameter by 10 m deep). Samples will be analyzed for filtered ortho-phosphate (FOP), total phosphorus (TP), dissolved nitrate (N03), ammonia (NH3), and total nitrogen (TN), Internal standards will be added to the subsamples of the water collected to insure quality control. All samples will be analyzed by Ecosystems Research Inc., a state certified nutrient analysis laboratory located in Logan. We will determine the TN:TP ratio in this water in order to predict if each lake is primarily limited by nitrogen or phosphorus.

Phytoplankton **- Abundance of phytoplankton in each of the lakes will be determined by measuring concentration of chla in a O-10 m integrated water column at the three stations. This sample will be collected with the tube sampler described above. Within 24 h, 100 ml aliquots of this sample will be sieved to separate particles <30 microns that are available to zooplankton grazing from those >30 microns that are unavailable. Each fraction will subsequently be filtered (0.45 urn) and the filters frozen. At** a **later date the chlorophyll from the filters will be dissolved in methanol and read with a fluorometer (Horn-Hansen and Rieman 1978). Acidified samples will also be measured for calculation of phaeophytin.**

Zooplankton - We will collect zooplankton samples using a 153 um **plankton net (25 cm opening). Two depth strata will be collected: O-10 m and whole water column samples. Three replicates of each depth sample will be collected at** each lake. **Zooplankton will be analyzed for all crustacean species. Lengths of 50 individuals of each species will be measured (nearest 0.05 mm) to estimate size distribution. The data will be reported in terms of density, biomass and size distribution for each species in each depth strata. Biomass will be estimated using published length-dry weight regressions (Dumont et al. 1975). Biomass of zooplankton greater than 0.3 mm in length and the ratio of copepod to cladoceran zooplankters will also be calculated, as these parameters have demonstrated to be of importance for juvenile sockeye growth (Koenings et al. 1989).**

1992 Research Plan

We will sample the lakes once in April to determine winter limnological conditions under the ice. These samples will follow the protocol outlined under the 1991 research plan. Beginning at ice-out and extending through late-June, we will sample the lakes at weekly intervals. From July through September we will sample the lake at bi-weekly intervals. We anticipate making 12 trips to the lakes during 1992. Sampling procedure will be similar to those proposed for 1991 with the following exceptions:

Bathymetric mapping - We will construct depth-contour lake maps for Redfish Stanley and Petit lakes using as King 70 kHz echosounder equipped with a strip chart. We will sample along predesignated transects set up at approximately 100 m intervals across the lakes. We will use a Loran C unit to describe transects if possible. If nearby mountains make use of the Loran impossible, we will use landmarks taken from U.S.G.S. 7.5' topographic maps to locate transects. These contour maps will allow us to construct a hypsographic curve for each lake so that volumes of individual depth strata can be calculated. This information is necessary in constructing nutrients budgets.

Physical parameters and oxygen - In addition to measuring temperature and oxygen, we will also measure light intensities (photosynthetic active radiation, PAR) at l-m depth intervals down to the 1% of surface light intensity. These light measurements will allow us to estimate the volume of the euphotic zone.

Nutrient budgets - We will estimate flow rates and TP concentrations in inflow and outflow streams and TP in the water column to construct a P-budget for each lake. Flows will be measured using a digital flow meter at l-m intervals across the stream, at 0.6 times the water depth (Wetzel and Likens 1989). TP will be measured in water samples collected from the epilimnion, metalimnion and hypolimnion of each lake. Epilimnetic samples will be collected with tube sampler, and deeper samples will be collected with a pump sampler.

Nutrients - We will measure the same suite of nutrients as in 1991. In addition to collecting surface waters, we will sample the metalimnion and hypolimnion of each lake with an electric pump.

Phytoplankton - In addition to epilimnetic tube samples, we will collect water for chlorophyll analysis from the metalimnion and hypolimnion of each lake using a pump sampler. From each water sample collected for chlorophyll we will also preserve a 50 ml sample in Lugols for possible later identification of species composition. We will estimate chlorophyll concentration from each sample and conduct species counts from selected samples.

Because the lakes are likely nutrient limited, and have relatively clear epilimnions, we expect that much of the chlorophyll will be located in "deep-chlorophyll maxima" in the metalimnion. Nutrient levels are somewhat higher there, and light is sufficient to allow low levels of photosynthesis. To some degree this concentration of chlorophyll may be unimportant because light levels are inadequate to promote much primary production (Reynolds 1984, Tilzer 1990). Nevertheless, we will carefully stratify our chlorophyll sampling by depth to avoid confounding the results from the different layers.

Zooplankton - We will collect triplicate epilimnetic and whole-water column tows as in 1991. In addition to the analyses proposed for 1991, we will also estimate birth rates of the cladocerans species by estimating the mean number of eggs per adult female in the population. These birth rates will allow us to estimates production of the cladocerans. These estimates of production in each lake (Koenings et al. 1989).

Nutrient bioassay and grazing experiments - These experiments are designed to assess whether nutrient limitation or zooplankton grazing limits phytoplankton growth at any given time. An experiment will be conducted in each of the lakes at three times during the season; early June, mid-July, and late August. Experimental protocol follows Elser and Goldman 91991) as briefly described below. The experiments will be conducted in 20-l opaque polyethylene mesocosms with treatments consisting of a factorial design of nutrient additions and zooplankton grazers. Two replicates of each treatment will be established. The treatments consist of a control (ambient phytoplankton, no additional nutrients, and most of the zooplankton removed by running water samples through a 153 um plankton net), a nutrient addition treatment (ambient phytoplankton plus 50 ug P / 1 and 200 ug N / l) a zooplankton treatment (ambient phytoplankton and zooplankton, and nutrient X zooplankton treatment (ambient phytoplankton plus ambient zooplankton plus 50 ug/l P and 200 ug/1 N). In a small percent of oligotrophic lakes, phytoplankton production is limited by trace nutrients. To determine whether this is occurring in any of the 5 Stanley Basin nursery lakes, a fifth treatment will be added will be added which will consist of adding a suite of trace nutrients to ambient phytoplankton. Each of these mesocosms will be suspended in the water column at the depth of the 50% light level. Each experiment will run 6 days. Chlorophyll levels and zooplankton species and size compositions will be measured from each of the mesocosms at the beginning and end of each experiment. Results from these experiments will allow us to determine periods of the year when nutrients additions will likely result in enhanced algal production.

These proposed nutrient-grazer experiments are somewhat different from the standard bioassay (Wetzel and Likens 1989) used to access nutrient limitation. It is unlikely that a single nutrient is limiting phytoplankton growth. Future lake fertilization will likely involve a mixture of N and P and possibly a trace nutrient. Knowing which of these nutrients limits phytoplankton is unnecessary because the addition of P to a P-limited community will, for example, very likely drive the system towards limitation by another nutrient. Our approach is to document the seasonal response of phytoplankton populations to additions of N, P and trace nutrients,

In addition to documenting nutrient limitation, our experiments will allow us to assess the degree to which zooplankton grazers interact with nutrient additions to define phytoplankton growth rates. Our experiments examine the response of phytoplankton to nutrient additions under conditions of both high and low levels of herbivorous zooplankton. These conditions will likely mimic zooplankton concentrations under present low densities of planktivorous fish and higher levels once sockeye populations are enhanced. Measurement of zooplankton species composition and biomass at the beginning and end of each experiment will also allow us to determine how rapidly zooplankton populations respond to nutrient additions in each of the five lakes.

Sockeye growth potential - In each of the lakes we will assess the potential for sockeye growth using a bioenergetics model constructed and validated for sockeye salmon (Beauchamp et al. 1989). Inputs to the model include the initial weight of stocked juveniles, temperature the fish will likely reside at in the water column. The temperature inputs will be derived from our temperature profiles assuming juvenile sockeye choose water temperatures according to the behavior model Levy (1990). The growth response of juvenile sockeye to different zooplankton densities will be derived from investigations we are currently conducting where growth of juvenile kokanee salmon is being measured along a gradient of zooplankton concentrations (Teuscher and Luecke, unpublished data). The bioenergetics model allows us to integrate the effects of temperature and zooplankton food resources and has been used extensively by one of the principle investigators (Luecke et al. 1990). Comparison of the growth potential sockeye in each of the five lakes will allow us to predict which of the lakes would be best candidates for initial sockeye rehabilitation.

APPENDIX B. Limnological analysis of Sawtooth Valley Lakes, Idaho, with respect to potential rehabilitation of sockeye salmon.

PRELIMINARY REPORT

LIKNOLOGICAL ANALYSIS OF SAWTOOTH VALLEY LAKES, IDAHO, WITH RESPECT TO POTENTIAL REHABILITATION OF SOCKEYE SALMON

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January 28, 1992

INTRODUCTION

Limnological parameters were measured on five lakes within the Sawtooth Valley, Idaho (Custer and Blaine Counties), during October 20-22, 1991. We sampled the lakes to attain some preliminary information on limnological conditions prior to beginning detailed investigations to examine potential production of juvenile sockeye salmon in the lakes in 1992. The five lakes sampled were Redfish, Alturas, Pettit, Stanley and Yellowbelly. These lakes lie at elevations between 6,500 and 7,100 feet (1980-2160 m) at the edge of Sawtooth Wilderness area in south-central Idaho. Limnological parameters measured are listed in Table 1. All samples were collected in the deeper section of each lake.

PHYSICAL PARAMETERS

Temperature - Temperature profiles in each lake were measured with a YSI thermistor. All five lakes were still thermally stratified in late October (Figure 1). Surface temperatures ranged from 9.4°C in Stanley Lake to 12.2°C in Pettit Lake. The epilimnions extended from the surface to 12-16 m deep. The hypolimnion began at approximately 18 m in Stanley and Yellowbelly Lakes and at approximately 25 m in Redfish, Alturas and Pettit Lakes (Figure 1). Hypolimnetic temperatures were between 4 and 5.5°C in all five lakes.

Lisht -The three deeper lakes (Redfish, Alturas, and Pettit) had Secchi transparencies ranging from 16 to 19 m, whereas the shallower lakes (Stanley and Yellow Belly) had'transparencies between 10 and 12 m (Figure 1; Table 2).

Light penetration was measured in Pettit and Redfish Lakes with a LiCor radiometer calibrated to measure photosynthetic active radiation (400-700 nm). In Redfish Lake the extinction coefficient was estimated to be 0.11 between 0 and 19 m, whereas it increased to 0.17 between 19-27 m. These results suggest that more lightabsorbing particles were present in the metalimnion of Redfish Lake during the sampling period. In Pettit Lake the extinction coefficient was estimated to be 0.155 and was relatively constant throughout epilimnetic and metalimnetic layers. If we assume that active photosynthesis occurs to the 1% light level, we estimate that the photic zones of Redfish and Pettit lakes during October extended to 33 and 30 m, respectively.

CHEMICAL PARAMETERS

Oxvaen - Oxygen profiles demonstrated that a fair amount of oxygen depletion had occurred in four of the five lakes sampled (Figure 1). Only in Redfish Lake were bottom waters near saturation. In Pettit and Stanley Lakes a substantial volume of water was near anoxia. Low oxygen concentrations also occurred near the bottom of Alturas and Yellowbelly Lakes.

A metalimnetic peak in oxygen concentration occurred in Alturas, Pettit and Yellowbelly Lakes. These peaks were likely due to primary production occurring in the metalimnion where there was still sufficient light for photosynthesis (Figure 2), and elevated nutrients relative to the epilimnion.

Nutrients - Nutrient analyses were performed by Ecosystems Research Inc., a Utah-certified water analysis laboratory. Three forms of nitrogen and two forms of phosphorus, the nutrients most likely to be limiting to phytoplankton growth, were measured in water collected from O-9 m in each lake. Total nitrogen and total phosphorus provide an estimate of the pools of these nutrients present in the epilimnion. Unfiltered lake water was used for these analyses. Measurements of nitrate (NO_3), ammonia (NH_3) and ortho-phosphate (PO_4) provide estimates of the nutrients that are instantaneously available to phytoplankton. Filtered lake water (0.45 urn) was used for these analyses. Nutrient analyses were performed according to the procedures described in Adams (1991). Phosphorus was measured calorimetrically using the molybdate -

ascorbic acid procedure. Total nitrogen was analyzed after persulfate digestion, nitrate was reduced in a cadmium column, and ammonia was measured using an indophenol reaction.

Both forms of phosphorus were extremely low in all lakes (Table 3). Ortho-phosphate was below the detection limit of the analytical method (≤ 1 ug l^{-1}) in each lake, and total phosphorus was detected in only Alturas, Pettit, and Yellowbelly lake water. We suspect that the extremely low total P levels for Redfish and Stanley lake may have resulted from analytical or filtration errors. Total nitrogen concentrations were higher than expected, ranging from 117 ug l^{-1} in Pettit to 562 ug l^{-1} in Yellowbelly. Nitrate levels were low ranging from 2 ug l^{-1} in Alturas to 7 ug 1" in Redfish Lake. Ammonia levels were higher than anticipated ranging from 60 ug l^{-1} in Stanley to 34 ug l^{-1} in Alturas Lake. The high values for total nitrogen coupled with the relatively low values for NH,, and particularly NO,, indicate that much of the nitrogen exists in organic forms.

Ratios of total nitrogen to total phosphorus are high for all the lakes, ranging from 33 in Yellowbelly to 261 in Stanley (Table 3). These ratios indicate that phytoplankton populations are likely not limited by nitrogen. These high ratios may be the result of anomalous nitrogen or phosphorus estimates from the laboratory analyses. Additional analyses will be performed to ascertain the reliability of these measurements.

BIOLOGICAL PARAMETERS

<u>Chlorophyll</u> - Chlorophyll <u>a</u> measurements were made on integrated O-9 m epilimnetic water samples from each of the five lakes (Table 2a). In Redfish Lake additional water samples for chlorophyll analyses were collected with a Van Dorn bottle from 15, 25 and 85 m. Samples were filtered on 0.45 m membrane filters, frozen, and subsequently extracted in boiling methanol and analyzed fluorometrically for chlorophyll a and phaeophytin (Holm-Hansen and

kiemann 1978). Chlorophyll a levels were low in all the lakes, ranging from 0.43 ug l^{-1} in Pettit to 0.86 ug l^{-1} in Stanley Lake. The depth profile of chlorophyll in Redfish Lake (Table 2b) indicates a metalimnetic peak in chlorophyll a at 25 m. Additional epilimnetic water samples were fractionated with 30-um Nitex netting to determine algal fractions readily available for zooplankton grazing (< 30 urn), and those that would be larger and therefore more difficult to graze. In all lakes except Alturas, greater than 89% of the chlorophyll was in a size fraction $\leq$ 30 urn. In Alturas, 62% of the algal chlorophyll was in this fraction, and 38% in the larger fraction.

Secchi disk transparency varied inversely with chlorophyll a concentration in the five lakes. Although the relationship was not statistically significant ($f_{1,3}$=2.37, p=O.22), among lake variation in chlorophyll concentration explained 44% of the variation in Secchi transparency. A similar relationship with more data points would likely yield significant results.

Zooolankton - Zooplankton was collected with a metered plankton net (0.5-m diameter, 74 um mesh) from the deepest region of each lake. In each lake vertical tows were made at three stations from the bottom to the surface. The stations were separated by approximately 250 m in the smaller lakes, and 500 m in the larger ones. Mean depths of tows were as follows: Redfish - 84 m; Alturas - 49 m; Pettit - 50 m; Yellowbelly - 23 m; Stanley - 22 m.

Zooplankton concentrations were low in all five lakes. Rotifers were present in all samples but were not counted as they are not used extensively as food for juvenile sockeye salmon. The cladocerans Daphnia rosea, Bosmina lonairostris, and Holooedium aiberum were present in all five lakes. The density of Daphnia was lowest in Alturas (0.1 l^{-1}) and highest in Yellowbelly Lake (4 l^{-1}; Figure 3). The density of Bosmina was variable, being high in

'Alturas and low in the other lakes. The cyclopoid copepod *Macrocyclops* sp. was present in all lakes except Yellowbelly. A second, as yet unidentified, cyclopoid copepod was present in samples from Redfish and Alturas Lakes. The cyclopoid densities shown in Figure 3 are for combined counts of the two cyclopoid species. Nauplii were counted and sized separately from the copepodite life history stages.

The size distributions of crustacean zooplankton were similar in all lakes except Alturas (Figure 3). In Alturas, mean lengths of *Daphnia* and cyclopoid copepods were approximately 60% of lengths of these taxa in the other lakes. Lengths of *Bosmina* and *Holopedium* were similar in all lakes.

IMPLICATION OF RESULTS FOR SOCKEYE SALMON PRODUCTION

Measurements of Secchidepths, chlorophyll concentrations, and nutrient levels in the lakes all indicate that these systems are highly oligotrophic (Wetzel 1983), an expected finding given the geology and lack of pollution in the drainage basins. Given the high light penetration it is likely that the low productivity is caused by nutrient limitation. Additionally, the higher chlorophyll levels, increased oxygen concentrations and increased light attenuation in the metalimnion of some of the lakes also suggest that nutrient availability was limiting phytoplankton growth in the epilimnion in October. The nitrogen to phosphorus ratio suggests that all of the lakes should be phosphorus limited. These preliminary data indicate thatnutrientenhancement bioassays performed next summer will demonstrate that lake productivity will be stimulated significantly by fertilization.

The low oxygen concentrations present in the hypolimnion of Alturas, Pettit, Stanley and Yellowbelly Lakes was surprising given the other indices that demonstrate that the lakes are highly oligotrophic. These results suggest that the lakes may not completely destratify each spring and/or autumn, so that the low oxygen levels could be the result of more than one seasons's respiratory demand in the hypolimnion and sediments. Lakes that are protected from wind sometimes fail to mix completely during the annual thermal cycle. Pettit, yellow Belly and Stanley Lakes are all reasonably protected from wind and had low oxygen concentrations in their hypolimnions. Alturas, and particularly Redfish Lake have longer fetches than the other lakes, and they also had higher hypolimnetic oxygen concentrations. This supports the hypothesis that the protected lakes may have failed to mix in one or more season.

Sockeye salmon would not likely enter water with oxygen concentrations below 5 mg l^{-1}. If substantial volumes of water continue to have low concentration of oxygen, available habitat for juvenile sockeye salmon would be reduced and potential sockeye production in these lakes would be diminished. Because the hypolimnion of a lake may serve as a refuge from predation for sockeye salmon (Levy 1990), the inaccessibility of the deep water could be particularly significant if predators are abundant in the lakes. Additionally, if a lake fails to mix each fall and spring, it would limit the annual recycling of plant nutrients from the hypolimnion back into the photic zone, and this would reduce overall primary production and hence production of fish. We will examine oxygen concentrations throughout the water column this coming April to determine if the lakes thoroughly mixed prior to freezing in 1991. If the lakes do not mix thoroughly each year, oxygen concentrations would be an important variable to consider in assessing potential production of sockeye among the five lakes.

Concentrations of total phosphorus and nitrate were lower in Redfish and Alturas in 1991 compared to values reported for the early 1980's (Bowles and Cochnauer 1984). This difference could result from samples taken at different times of the year or from different depth strata. It is not clear whether nutrient levels have decreased in recent years when returns of adult sockeye salmon have been negligible.

Differences in the density and size distribution of zooplankton among lakes suggests that growth rates of stocked juvenile sockeye would vary tremendously among the lakes. The low density and small size of Daphnig in Alturas Lake indicates that growth of stocked sockeye juveniles would be relatively low in that system. Yellowbelly, Stanley, Redfish and Pettit Lakes appear to have sufficient quantities of large zooplankton to support growth of juvenile sockeye.

The observed gradient in abundance and size of zooplankton in the five lakes likely derives from differences in abundance of zooplanktivorous fish. Hydroacoustic surveys conducted in September 1991 indicated that fish densities were four times higher in Alturas compared to Redfish Lake (Luecke and Wurtsbaugh 1992). The relatively small differences *in* chlorophyll concentrations that occurred among the lakes would not likely result in the large differences observed in zooplankton composition.

These preliminary finding from October 1991 suggest that the five lakes may have very different capacities for eventual sockeye production. Redfish and Yellowbelly Lakes would appear to have the greatest production potential. Zooplankton food would likely limit sockeye growth in Alturas, whereas oxygen conditions might restrict stocked juveniles in Pettit and Stanley Lakes from the hypolimnetic zones and this might increase mortality rates if predators are abundant. Nutrient additions would likely enhance sockeye production in all the lakes. These results will help provide guidelines for assessing the seasonal variation in limnological parameters in 1992 that may impact future production of sockeye salmon.

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Table 1. Limnological parameters measured on five lakes October 20-22, 1991.

Measurement	Method
<u>PhysicaL</u>	
Temperature profiles	YSI meter
Light profiles	Licor meter
Transparency	Secchi disk
<u>Chemical</u>	
Oxygen profile	YSI meter
Total phosphorus	Spectrophotometer
Ortho-phosphate	"
Total nitrogen	"
Nitrate	"
Ammonia	"
<u>Biological</u>	
Chlorophyll <u>a</u>	Fluorometer
Zooplankton	Vertical net tow

Table 2a. Secchi disk transparencies and chlorophyll a concentrations in five lakes in the Sawtooth Valley, Idaho on 20-22 October 1991. Chlorophyll concentrations were measured in a O-9 m integrated water sample. Numbers in parentheses refer to standard deviations of 3 chlorophyll measurements.

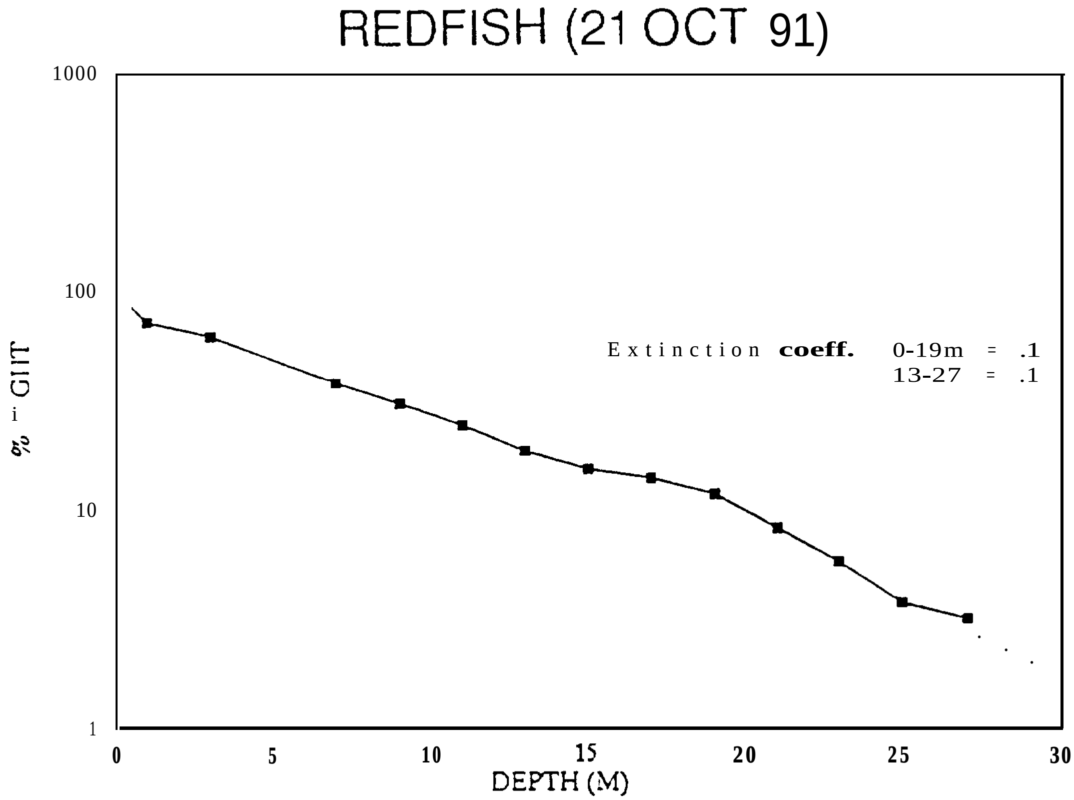
	Secchi (m)	Chlorophyll a (ug l^{-1})
Redfish Lake	18.8	0.62 (0.01)
Alturas Lake	16.5	0.75 (0.11)
Pettit Lake	19.3	0.43 (0.09'
Yellowbelly Lake	11.9	0.60 (0.01)
Stanley Lake	10.1	0.86 (0.09)

Table 2b. Depth profile of chlorophyll a concentration in Redfish Lake on October 21, 1991. Means and (standard deviation) of three replicates are shown.

Depth (m)	Chlorophyll a (ug l^{-1})
o-9	0.62 (0.01)
15	0.35 (0.01)
25	0.76 (0.04)
85	0.26 (0.03)

Table 3. Nutrient concentrations measured in epilimnetic water samples from five lakes October 20-22, 1991. Water was collected from 0-9 m. Concentrations are expressed as ug l^{-1}. Minimum detectable concentration is 1 ug l^{-1}. N/P refers to the ratio of TN to TP.

	LAKE				
	Redfish	Alturas	Pettit	Yellowbelly	Stanley
NO3	7	2	4	3	3
NH^4	47	35	51	45	60
TN	243	507	117	562	522
O-PO4	<l	<l	<l	<1	<l
TP	<1	11	2	17	<l
N/P	243	46	59	33	522



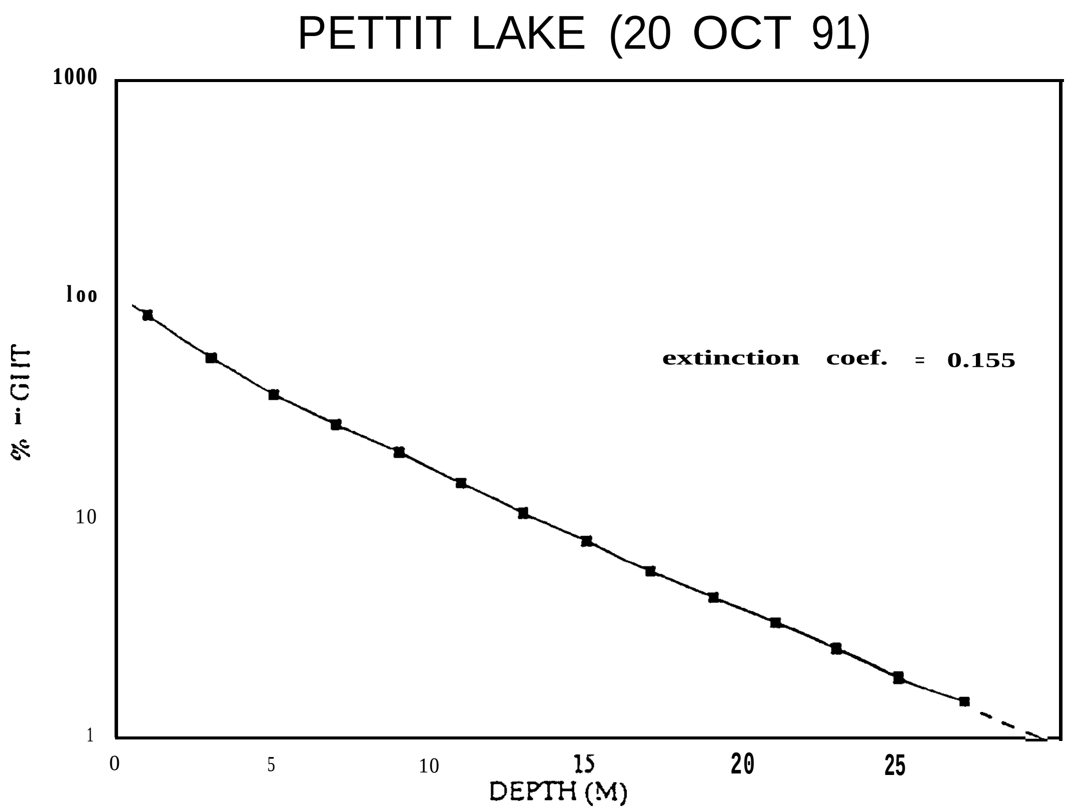


Figure 2. Light extinction profiles in Redfish and Pettit Lakes in October 1991. Vertical light extinction coefficients were calculated by linear regression of In-transformed regressions of light intensity over the specified depth ranges.

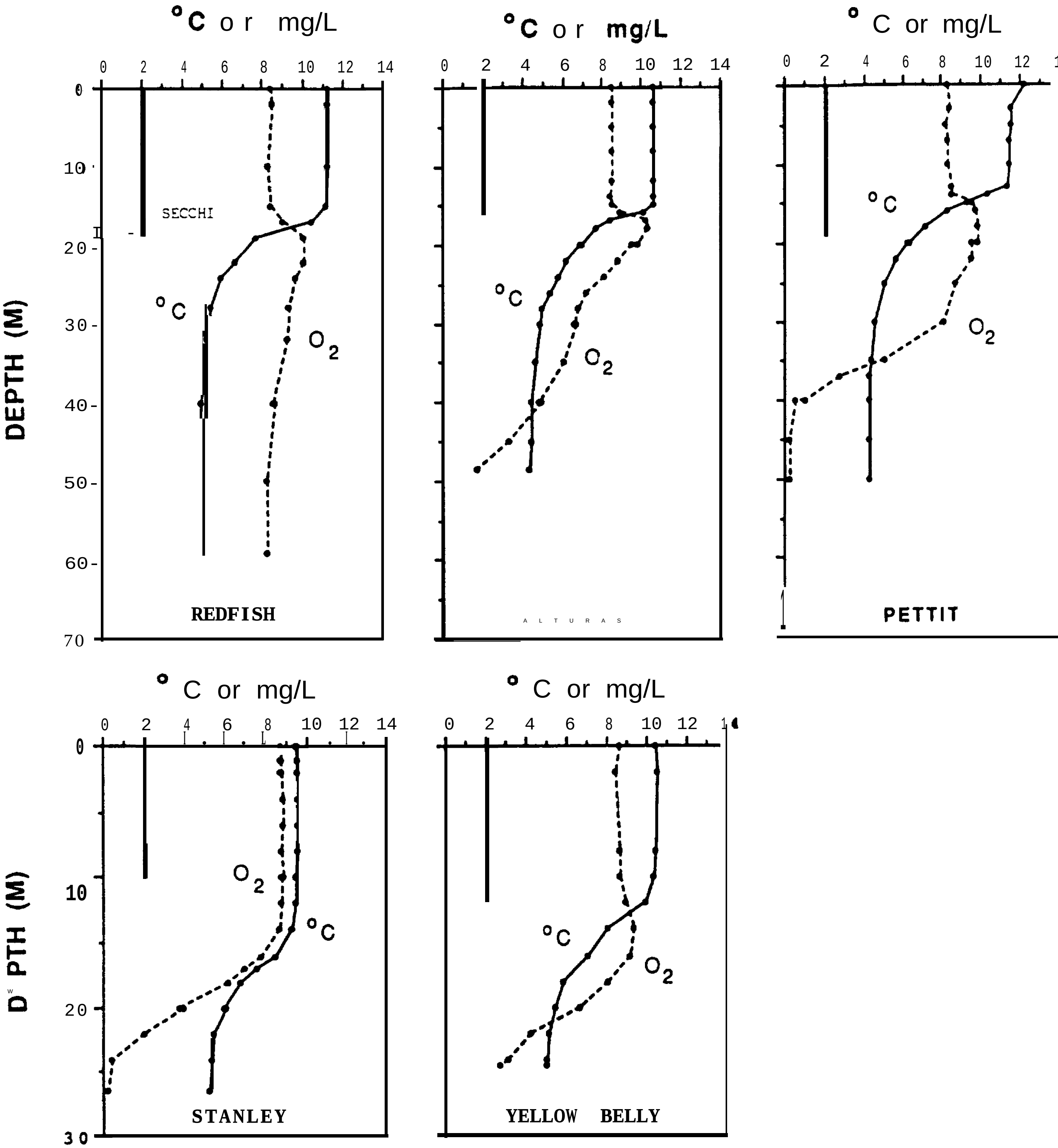


Figure 1. Secchi depths, and temperature and oxygen profiles of Sawtooth Valley lakes measured on 20-22 October, 1991.

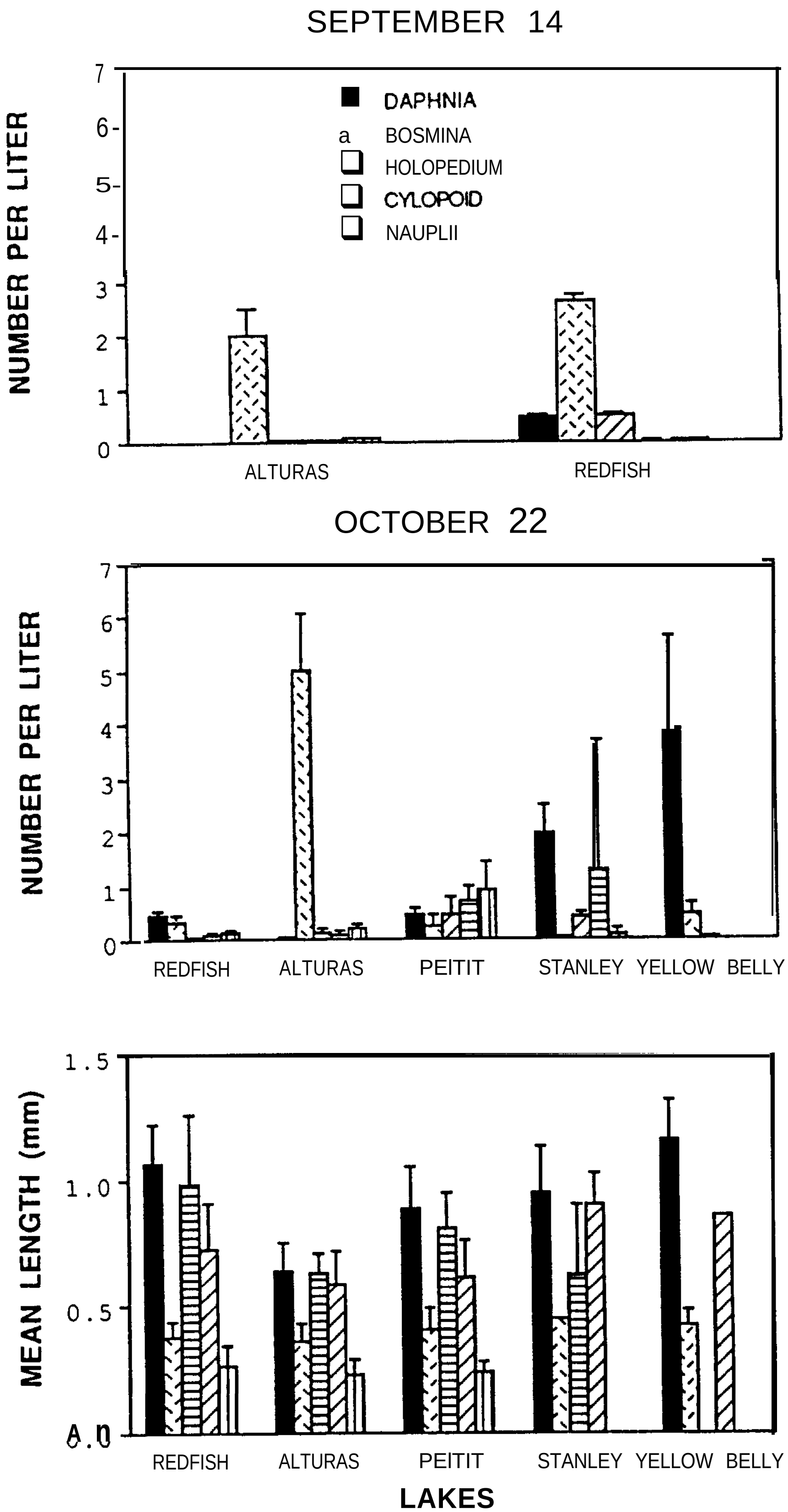


Figure 3. Densities and mean lengths of zooplankton in Sawtooth Valley lakes collected during the fall of 1991. Top: Zooplankton densities in Alturas and Redfish lakes on 14 September. These data were collected during the hydroacoustic surveys of these two lakes (Luecke and Wurtsbaugh 1991). **Middle:** Zooplankton densities in all five lakes on 20-22 October 1991. Bottom: Mean lengths of each zooplankton taxa on 20-22 October. **Means and** ranges of three replicates are shown for density, and the **mean and** SD 10 or more measurements of lengths are given.

APPENDIX C.. Summary of emergent kokanee fry trapping for 1992 In Alturas and Fishhook Creek by date. Codes:Trap- l=flxed trap, 2=roving trap; System- l=Flshhook Creek, 2=Alturas Lake Creek.

SYSTEM	YEAR	MONTH	DAY	TRAP	TEMP	FISH	BOTH TRAPS
2	92	4	29	1	3	0	
2	92	4	29	2	3	0	0
2	92	5	1	1	1.5	0	
2	92	5	1	2	1.5	0	0
2	92	5	3	1	2	0	
2	92	5	3	2	2	0	0
2	92	5	4	1	2.5	0	
2	92	5	4	2	2.5	0	0
2	92	5	5	1	2.5	0	
2	92	5	5	2	25	0	0
2	92	5	13	1	3	0	
2	92	5	13	2	3	0	0
2	92	5	15	1	2	3	3
2	92	5	17	1	4	0	0
2	92	5	18	1	2	0	0
2	92	5	20	1	2	2	2
2	92	5	21	1		0	0
2	92	5	23	1		0	0
2	92	5	27	1	5	2	
2	92	5	27	2	5	0	2
2	92	5	28	1	5	9	
2	92	5	28	2	5	16	2s
2	92	5	29	1	5	6	6
2	92	5	31	1	6	9	
2	92	5	31	2	6	2	11
2	92	6	2	1	6	7	
2	92	6	2	2	6	5	12
2	92	6	3	1		15	
2	92	6	3	2		7	22
2	92	6	4	1		4	
2	92	6	4	2		11	15
2	92	6	5	1		8	
2	92	6	5	2		9	17
2	92	6	7	1		9	
2	92	6	7	2		3	12
2	92	6	8	1		13	
2	92	6	8	2		8	21
2	92	6	10	1		25	
2	92	6	10	2		7	32
2	92	6	12	1		2	
2	92	6	12	2		0	2
2	92	6	14	1		8	
2	92	6	14	2		2	10
2	92	6	16	1		8	
2	92	6	16	2		a	12
2	92	6	18	1		6	
2	92	6	18	2		3	9
2	92	6	19	1		6	
2	92	6	19	2		1	7
2	92	6	22	1		1	
2	92	6	22	2		0	1

SYSTEM	YEAR	MONTH	DAY	TRAP	TEHP	FISH	BOTH TRAPS
1	92	4	21	1	3	11	11
1	92	4	23	1	1	6	
1	92	4	23	2	1	11	17
1	92	4	25	1	4	24	
1	92	4	25	2	4	2	26
1	92	4	27	1	5	34	
1	92	4	27	2	5	24	58
1	92	4	29	1	5	11	
1	92	4	29	2	5	1	12
1	92	4	30	1	3.5	10	
1	92	4	30	2	3.5	18	28
1	92	5	1	1	2.5	25	
1	92	5	1	2	2.5	32	57
1	92	5	3	1	4	61	
1	92	5	3	2	4	3	64
1	92	5	4	1	3	52	
1	92	5	4	2	3	1	53
1	92	5	5	1	4	69	
1	92	5	5	2	4	39	108
1	92	5	7	1	4	50	
1	92	5	7	2	4	0	so
1	92	5	9	1	3	39	
1	92	5	9	2	3	12	51
1	92	5	11	1	3	98	
1	92	5	11	2	3	48	146
1	92	5	13	1	4	22	
1	92	5	13	2	4	0	22
1	92	5	15	1	6	169	
1	92	5	15	2	6	94	263
1	92	5	17	1	6	260	
1	92	5	17	2	6	25	285
1	92	5	18	1		161	
1	92	5	18	2		7	168
1	92	5	19	1	6	353	
1	92	5	19	2	6	215	568
1	92	5	20	1		32	
1	92	5	20	2		7	39
1	92	5	21	1		81	
1	92	5	21	2		2	83
1	92	5	23	1	6	146	
1	92	5	23	2	6	3	149
1	92	5	27	1		55	
1	92	5	27	2		21	76
1	92	5	28	1		116	
1	92	5	28	2		118	234
1	92	5	29	1	6	185	
1	92	5	29	2	6	6	191
1	92	5	31	1	6	125	
1	92	5	31	2	6	116	241
1	92	6	2	1	6	78	
1	92	6	2	2	6	33	111
1	92	6	3	1		110	

1	92	6	3	2	26	136
1	92	6	4	1	104	
1	92	6	4	2	97	201
1	92	6	5	1	60	
1	92	6	5	2	5	65
1	92	6	7	1	**15**	
1	92	6	7	2	12	27
1	92	6	8	1	28	
1	92	6	8	2	13	41
1	92	6	10	1	6	
1	92	6	10	2	9	15
1	92	6	12	1	1	
1	92	6	12	2	0	1
1	92	6	14	1	0	
1	92	6	14	2	0	0
1	92	6	16	1	1	
1	92	6	16	2	0	1
1	92	6	18	1	0	
1	92	6	18	2	0	0
1	92	6	19	1	2	
1	92	6	19	2	0	2
1	92	6	22	1	0	
1	92	6	22	2	0	0

APPENDIX D. Adult Kokanee spawner live counts (1992) in Flshook Creek and Alturas Lake Creek by transect and date System codes l=Fishook Creek. 2=Alturas Lake Creek.

Year	Month	Day	System	Transect	Number	Total	Dead
1992	8	6	1	1	0	1	0
				2	0		
				3	0		
				4	1		
				5	0		
				6	0		
				7	0		
				8	0		
				9	0		
1992	8	11	1	1	0	181	0
				2	7		
				3	0		
				4	17		
				5	0		
				6	12		
				7	7		
				8	134		
				9	4		
1992	8	14	1	1	0	323	0
				2	8		
				3	1		
				4	22		
				5	0		
				6	15		
				7	36		
				8	236		
				9	5		
1992	8	17	1	1	0	1701	0
				2	55		
				3	45		
				4	53		
				5	349		
				6	62		
				7	149		
				8	983		
				9	5		
1992	8	21	1	1	1	2571	0
				2	240		
				3	176		
				4	188		
				5	362		
				6	172		
				7	206		
				8	1188		
				9	30		

Year	Month	Day	System	Transect	Number	Total	Dead	
1992	8	24	1	1	1	4574	0	
				2	683		0	
				3	364		0	
				4	612		7	
				5	321		2	
				6	261		2	
				7	281		5	
				8	1960		26	
				9	91		0	
1992	8	28	1	1	20	4242	0	
				2	718		1	
				3	367		2	
				4	320		6	
				5	342		6	
				6	317		6	
				7	269		3	
				8	1562		17	
				9	327		0	
1992	8	31	1	1	29	4033	0	
				2	697		2	
				3	503		4	
				4	243		3	
				5	197		4	
				6	286		1	
				7	418		7	
				8	1439		19	
				9	221		0	
1992	9	2	1	1	9	2969	0	
				2	473		9	
				3	213		6	
				4	307		14	
				5	429		19	
				6	183		12	
				7	149		6	
				8	1176		32	
				9	30		2	
1992	9	9	1	1	0	3276		NC
				2	586			
				3	209			
				4	272			
				5	302			
				6	262			
				7	248			
				8	1360			
				9	37			

Year	Month	Day	System	Transect	Number	Total	Dead	
1992	9	17	1	1	0	595		NC
				2	12			
				3	64			
				4	58			
				5	59			
				6	46			
				7	54			
				8	301			
				9	1			
1992	8	6	2	1	2	2	0	
				2	0			
				3	0			
1992	8	11	2	1	2	2	0	
				2	0			
				3	0			
1992	8	14	2	1	0	0	0	
				2	0			
				3	0			
1992	8	18	2	1	9	9	0	
				2	0			
				3	0			
1992	8	20	2	1	45	45	0	
				2	0			
				3	0			
1992	8	24	2	1	71	71	0	
				2	0			
				3	0			
1992	8	26	2	1	72	72	0	
				2	0			
				3	0			
1992	8	28	2	1	13	45	1	
				2	32			
				3	0			
1992	8	31	2	1	9	23	0	
				2	14			
				3	0			
1992	**9**	2	2	1	7	18	0	
				2	11			
				3	0			
1992	**9**	4	2	1	0	0	0	
				2	0			
				3	0			
1992	**9**	9	2	1	0	0	0	
				2	0			
				3	0			
1992	**9**	16	2	1	0	0	0	
				2	0			
				3	0			
1992	**9**	28	2	1	0	0	0	
				2	0			
				3	0			

APPENDIX E . Summary of Sawtooth Valley gillnet effort. Sept.1992.

Fish Species. Bull trout=1 : Ralnbow trout=2: Suckers=3; Squawflsh=4: Whileflsh=5; Kokanee=6
Brook Trout=7; Shiners=8 lake Trout=9
System Code: Redfish Lake=l; Abras Lake= 2. pettit Lake=3; Stanley Lake=4: Yellow Belly Lake=5
Net Oeph Codes: l=shallow (2-10 M). 2=intermediate (11-20 M); 3=deep (21-40M)
CPE= Fish/l2ORlhr

Year	System	Net Depth	Species	CPE
1992	2	1	1	0.143
1992	2	1	1	0.09
1992	2	1	1	0.043
1992	2	1	1	0
1992	2	2	1	0.091
1992	2	2	1	0.128
1992	2	2	1	0
1992	2	2	1	0
1992	2	2	1	0.083
1992	2	2	1	0.163
1992	2	3	1	0
1992	2	3	1	0.087
1992	2	3	1	0
1992	2	3	1	0.085
1992	2	3	1	0.1
1992	2	3	1	0.083
1992	2	1	2	0.048
1992	2	1	2	0
1992	2	1	2	0.426
1992	2	1	2	0.2
1992	2	2	2	0
1992	2	2	2	0.128
1992	2	2	2	0.213
1992	2	2	2	0.208
1992	2	2	2	0.167
1992	2	2	2	0.041
1992	2	3	2	0
1992	2	3	2	0.087
1992	2	3	2	0
1992	2	3	2	0
1992	2	3	2	0
1992	2	3	2	0
1992	2	1	3	0.213
1992	2	1	3	0.32
1992	2	1	3	1.09
1992	2	1	3	2.619
1992	2	2	3	2.619
1992	2	2	3	2.128
1992	2	2	3	0.17
1992	2	2	3	0.667
1992	2	2	3	2.26

1992	2	2	3	0735
1992	2	3	3	0.409
1992	2	3	3	0.087
1992	2	3	3	0136
1992	2	3	3	0
1992	2	3	3	0.033
1992	2	3	3	0
1992	2	1	4	0.851
1992	2	1	4	0.28
1992	2	1	4	1.952
1992	2	1	4	1.09
1992	2	2	4	0.091
1992	2	2	4	0.091
1992	2	2	4	0.979
1992	2	2	4	0.792
1992	2	2	4	1.042
1992	2	2	4	0.735
1992	2	3	4	0273
1992	2	3	4	0
1992	2	3	4	0
1992	2	3	4	0
1992	2	3	4	0
1992	2	3	4	0
1992	2	1	5	0
1992	2	1	5	0
1992	2	1	5	0
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1992	2	2	5	0.227
1992	2	2	5	0
1992	2	2	5	0.128
1992	2	2	5	0
1992	2	2	5	0
1992	2	2	5	0
1992	2	3	5	0.091
1992	2	3	5	0
1992	2	3	5	0.045
1992	2	3	5	0
1992	2	3	5	0
1992	2	3	5	0
1992	2	1	6	0
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1992	2	1	6	0
1992	2	2	6	0
1992	2	2	6	0.043
1992	2	2	6	0
1992	2	2	6	0
1992	2	2	6	0
1992	2	2	6	0
1992	2	3	6	0.136
1992	2	3	6	0
1992	2	3	6	0.045

1992	3	6	0
1992	3	6	0
1992	3	6	0
1992	1	2	0.2
1992	1	2	0.357
1992	1	2	0.279
1992	1	2	0.047
1992	2	2	0.2
1992	2	2	0
1992	2	2	0
1992	2	2	0
1992	2	2	0
1992	2	2	0.045
1992	2	2	0.045
1992	3	2	0
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1992	3	2	0
1992	3	2	0
1992	3	2	0
1992	1	6	0
1992	1	6	0
1992	1	6	0
1992	1	6	0
1992	2	6	0
1992	2	6	0.067
1992	2	6	0
1992	2	6	0.143
1992	2	6	0
1992	2	6	0
1992	2	6	0.091
1992	3	6	0
1992	3	6	0
1992	3	6	0
1992	3	6	0
1992	3	6	0
1992	1	7	0.6
1992	1	7	0.071
1992	1	7	0.047
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1992	2	7	0.333
1992	2	7	0.067
1992	2	7	0
1992	2	7	0.071
1992	2	7	0
1992	2	7	0.812
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1992	3	1	8	0
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1992	3	2	8	0
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1992	3	2	8	0
1992	3	2	8	0
1992	3	2	8	0.182
1992	3	2	8	0
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1992	3	3	8	0
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1992	4	1	2	0
1992	4	1	2	0.629
1992	4	1	2	0 789
1992	4	2	2	0
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1992	4	2	2	0
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1992	4	3	2	0
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1992	4	1	6	0
1992	4	1	6	0.057
1992	4	1	6	0
1992	4	2	6	0
1992	4	2	6	0
1992	4	2	6	0.053
1992	4	3	6	0
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1992	4	3	6	0
1992	4	3	6	0
1992	4	3	6	0
1992	4	1	7	0.424
1992	4	1	7	0.114
1992	4	1	7	0.263
1992	4	2	7	0
1992	4	2	7	0
1992	4	2	7	0
1992	4	3	7	0
1992	4	3	7	0
1992	4	3	7	0
1992	4	3	7	0
1992	4	3	7	0
1992	4	3	7	0
1992	4	1	9	0.182

1992	4	1	9	0171
1992	4	1	9	0.158
1992	4	2	9	0
1992	4	2	9	0.343
1992	4	2	9	0.263
1992	4	3	9	0.061
1992	4	3	9	0
1992	4	3	9	0.229
1992	4	3	9	0
1992	4	3	9	0
1992	4	3	9	0

APPENDIX F.

SNAKE RIVER SOCKEYE SALMON

AN ANALYSIS OF RELEASE STRATEGIES

February 1992

Sho-Ban Tribes

INTRODUCTION

A number of scenarios are being considered for the release of Snake River sockeye salmon (Oncorhvnchus nerka) progeny derived from a captive broodstock. The captive broodstock was obtained from 4 returning adult sockeye salmon (one female and three males trapped and spawned in the summer and fall of 1991, respectively). Additionally, progeny derived from 746 and 135 Redfish Lake and Alturas Lake O. nerka smolts, respectively, trapped in the spring of 1991 and reared to maturity will potentially be available for Snake River sockeye salmon rebuilding efforts.

Central to any plan for release of sockeye salmon juveniles is adequate rearing habitat. Currently limnological studies are being conducted on Redfish Lake and the other Sawtooth Valley lakes that were historical producers of sockeye salmon. This information will be used to identify potential fish rearing limitations and to make recommendations for remedial activities to increase production potential of the nursery lakes. Emphasis will be placed on food chain dynamics and fish production capability as it relates to increased primary production. In conjunction with this work, a plan to maximize survival of liberated captive broodstock progeny to returning O. nerka adults and the maintenance of subsequent life history patterns (i.e., spawning site selection) must be developed. Following are the basic strategies of in-lake fish releases that are available for consideration using progeny of the present captive broodstock:

1. Release of fingerlings (about 3 gm) into the nursery lake in the spring. The bulk of the rearing would occur in the lake under natural conditions. This strategy involves a natural rearing regime that would largely dictate fry to smolt survival and smolt outmigration timing.

2. Release of fingerlings into net pens placed in the nursery lake in spring. Fry would be fed until the fall turnover and released into the lake to overwinter under natural conditions. This option includes some natural rearing features while minimizing predation and increasing growth potential through to fall.

3. Release of fingerlings into net pens placed in the nursery lake in spring. Fry would be fed until smolt stage the following spring then released. Fry would over-winter in net pens. This option attempts to maximize fry to smolt survival in the context of natural physio-chemical lake conditions. This option still needs to be technically pursued to examine the feasibility of maintaining net pens through the harsh winter conditions of the Sawtooth Valley.

4. Hatchery rear fish to presmolt (about 9.5 gm) and release into the nursery lake in the fall. This option maximizes growth and minimizes mortality to the presmolt stage while maintaining some influence of the environment on subsequent smolt outmigration.

5. Hatchery rear fish until smolt stage and release them into the nursery lake in spring. This option would limit lake exposure to the period of time just prior to smolt outmigration to allow imprinting. Ideally, survival to smolt stage would be maximized. The possibility exists however, that snow and ice conditions would hamper transport and release of the smolts to the lake during the window of time that the fish would need to be released.

6. Raise the captive broodstock progeny to maturity and outplant adults in the lake to spawn naturally. This option maximizes the number of adults available to initiate a natural life history cycle for the next generation. It would also necessitate more hatchery space, and it increases the risks associated with captive rearing.

GENERAL REVIEW OF SUPPLEMENTATION

An appropriate strategy, or strategies, must be selected that will provide the greatest adult returns. However before proceeding to analyze the specifics of various release strategies it is wise to consider the problems associated with supplementation in general. A review of supplementation efforts on sockeye salmon and other salmonids done throughout the Northwest will provide an understanding of the advantages and disadvantages of each of the suggested strategies.

Anadromous fish have been stocked in the Pacific Northwest for many years. There have been reports of increasing adult returns from various types of planting strategies. Outplantings of smolts return the highest percentage of adults for both salmon and steelhead. However, there are mixed results on the ability to rebuild or increase natural runs by supplementing with hatchery fish.

Miller et al. (1990) reviewed 316 projects from unpublished literature and ongoing work and found that only 25 were successful for supplementing natural existing runs. Successes from outplanting hatchery fish were primarily in harvest augmentation. They did find that hatchery fish released into virgin areas, barren lakes, above falls or barriers, in new geographic areas, *or* directly into estuaries or coves did quite well.

Following are conclusions based on an extensive review of supplementation efforts to date gleaned from the Miller report:

- Introduced hatchery fish can augment the number of returning adults to a particular area, but if the factors which originally caused the natural runs to decline are not corrected, production will not significantly change. This concept is extremely relevant to the Snake River sockeye salmon recovery efforts. Comprehensive recovery efforts must include corrective measures for passage and flow problems, mixed stock harvest in the mainstem Columbia River and ocean fisheries, habitat problems associated with nutrient deficiencies in nursery lakes and passage barriers into the nursery lakes.

- In some cases the presence of additional hatchery adults can lead to increased exploitation, thus decreasing the natural production even faster. In some studies, wild/natural stocks were shown to be more viable than hatchery stocks. Thus, replacing wild/natural fish with hatchery fish, and cross breeding wild/natural and hatchery fish, can result in lower individual productivity (Steward and Bjornn 1990).

- Miller et al. also state that major changes in hatchery management must be made. Fish must be made as compatible with the environment (outplanting site) as possible. Changes that appear insignificant at the hatchery (e.g., rearing program, outplant timing, and marking) can seriously affect the success of supplementation.

In addition to the basic concepts of identifying and correcting the original causes of a stock's decline and improving hatchery effectiveness, Miller et al. found the following relevant relationships:

- Salmon species with a shorter freshwater life cycle show a higher success rate from hatchery supplementation, and have less negative impacts on wild/natural populations.

- In general, salmon and steelhead stocks close to the ocean with short migration distances responded more positively to supplementation than stocks with longer migration distances. In some cases, introducing hatchery stock to a river system a few kilometers closer to the estuary significantly increased the rate of adult returns.

- The stock of fish is an important factor to consider when supplementing. The closer the hatchery stock is to the supplemented stock or original natural stock, the better chances are for success. Ideally, the hatchery supplementation brood fish should be taken from the natural stock that is to be supplemented.

Figure 1 summarizes some of the factors that affect supplementation success.

Figure 1. General success of supplementation with hatchery fish to returning adult.

Good Success -->-------------->-------->------------>-----Poor Success
Increasing length of freshwater residency

Good Success -->-------------->-------------->-------------->-----Poor Success
Increasing distance from ocean

Good Success -->---------->------------>------------>----- Poor Success
Increasing distance between stocks used

Good Success -->------------>------------>------------>-----Poor Success
Lake rearing Main river rearing Stream rearing

From: Miller, et al. (1990).

THE ALASKA AND BRITISH COLUMBIA EXPERIENCE

Successful techniques for establishing, rebuilding and supplementing sockeye salmon populations have been developed in Alaska and British Columbia (BC). Sockeye salmon are planted into barren lakes or lakes with adult barriers, and to supplement existing stocks in Alaska. Lakes generally are only a few miles from salt water. A program of lake fertilization is done following a limnological study to identify needed nutrients. Natural broodstock are used where possible. Excellent adult returns have been realized with smolt releases. Sockeye salmon smolt releases are being expanded because of the success of these programs.

Most of these programs integrate lake fertilization with fry plantings of appropriate stocks. Some of these techniques summarized below may prove useful in rebuilding Columbia River sockeye populations (Miller et al., 1990). Following are survival rates or adult return rates of various stocking techniques:

- Sockeye salmon stocked in Summit Lake of the Gulkana River drainage as unfed fry have returned as adults at 0.8 percent (following exploitation).

- Some sockeye salmon smolt stockings into Big Lake have produced adult survivals of up to 35%.

- Planting eyed eggs in upper Thumb River, a tributary of Karluk Lake, has increased adult returns to Karluk Lake and spawners to upper Thumb River. Eyed egg survival to fry exceeds survival commonly obtained from natural spawners (White 1986).

- Fingerling sockeye salmon were successfully released into Hidden Lake, where spawning area was believed to be the limiting factor. Fingerling-to-smelt survival averaged about 20 percent and smolt-to-adult returns average around 15 percent (Litchfield and Flagg 1988).

- A streamside gravel incubator operation at Gulkana for sockeye and chinook salmon also appears to be working well. Groundwater from the stream is directed through large units of Kitoi egg boxes loaded with sockeye and chinook eggs. As fry hatch, they are washed into a trapping and enumeration area and from there outplanted. Fry hatch at a similar time as natural spawned eggs. This is a low technology, low cost method of salmon fry production.

It is evident from the above Alaska and BC examples, that releases of eggs, fry, fingerlings, and smolts all have been extremely successful. However, the Alaskan and BC release sites are generally very close to the ocean and bear little similarity to the conditions found in the Snake and Columbia rivers.

RELEASE METHODS

Release methods, such as time and size can have significant effects on fish survival, although the inter-relationship between factors is not well understood. Steward and Bjornn (1990) concluded that it is difficult to differentiate the effects of size of release from time of release. For the range of release sizes and dates typically available to hatchery managers, time of release apparently has a greater effect on survival than does size (Bilton et al. 1984; Mathews and Ishida 1989).

Eggs Egg plantings may reduce artificial selection pressures that may accompany hatchery operations, but it does not guarantee favorable results (Steward and Bjornn 1990). Although substantial mortality of outplanted eggs can be expected even under the best conditions, optimal results are obtained when fertilization and stocking mimic natural spawning times. No difference in the efficacy of sockeye salmon and steelhead survival using egg planting and releasing button-up fry was found (Foerster 1938 and Bjornn 1978).

Fry. Salmon stocks have been successfully supplemented with fry, particularly in productive, underseeded habitats (Bjornn 1978). Fry fed for a short period before release may survive better than unfed fry (Stewart 1963).

The Upper Adams River Experience

The population of sockeye salmon in the upper Adams River became extinct after a series of blockages prevented spawners from reaching their natal stream. Population rehabilitation efforts took place from 1949 to 1985. Egg and fingerling transplants from

1949 to 1975 resulted in very few returns to the river. However, from 1980 to 1984, a six-fold increase in spawners occurred. The increase was attributed to several factors. First, though the original transplants did not produce significant numbers of returning spawners, Williams (1987) speculates that they provided a seed population which was genetically fit for the Upper Adams watershed. Second, short term rearing was included in the 1980 brood program, thus giving the sockeye salmon fry an advantage over natural conspecifics. Third survival of natural sockeye salmon from much of the Thompson district has increased from 1980 to 1984.

The short term rearing involved placing the fry in polyethylene cones (Heard and Martin 1979). The cones were attached to a barge anchored near the mouth of the upper Adams River. Fry were fed freeze-dried calanoid copepods for 24-40 days depending on time from emergence to release. The fry were released into the lake at night. Size at release ranged from 26.3 mm fork length to 27.5 mm. Mortality ranged from 8.2% to 15.8% depending on time of emergence. Later emerging fry tended to be larger and experience lower mortality.

Presmolts and smolts. Size at release has also been found to correlate with post-stocking survival of older presmolts and smolts (Steward and Bjornn 1990). Koenings (1989) and Mayo (1990) looked at the survival of sockeye salmon smolts as a function of size at the time of outmigration. In Lake Washington, the average size of smolts is from 96 to 101 mm in length (range 70-120 mm) and the average survival over 19 years was 11.8% (range 4.1% - 22.9%). At Cultus Lake the highest survivals occur between 83 to 93 mm. In Alaska, Koenings concluded that the optimum size for survival is between 90 and 100 mm and ocean survival can be as high as 30 to 50%.

There is a strong correlation between sockeye salmon smolt size and ocean survival. From the above it appears that the optimum size ranges between 83 and 101 mm (4.7 gm to 7.0 gm). Koenings and Burkett (1987) and Klyashtorin and Smirnov (1989) have shown that smolts less than the optimum size have lower survival rates, but there is no advantage, or perhaps even a disadvantage, to having smolts larger than the optimum size.

Sockeye salmon smolts outmigrate from freshwater systems as underyearlings (less than one year old), as one check smolts (one year in freshwater), as two check smolts, and infrequently as three check smolts (Taylor, 1989). Most fry rear in freshwater lakes, but there are some sockeye salmon stocks that rear in river systems, especially underyearling smolts. Fish size and time of year are the underlying factors that determine when fish outmigrate. Taylor concludes that the age of the fish appears to have little influence on survival except as a function of size.

Smolt size is a function of water temperature as it relates to the organism's metabolism and to forage abundance and availability (Amend et al. 1990). In cold water systems with short growing periods, fry tend to be small and stay longer in the freshwater environment longer. Systems with a high abundance of fry, which overcrop the feed supply, also tend to have lower growth rates. This can affect lake residency time prior to smolt outmigration and smolt size at time of migration. The variable relationship between feed abundance and fry density at least partially explains the range in survival rates of sockeye salmon. High escapements followed by high fry densities may result in lower smolt to adult survival rates if growth opportunity is limited compared to fish in systems with lower fry densities and comparable growth opportunities.

Amend et al. assumed that the optimum survival occurs when smolts outmigrate at a 5 to 7 gm size in mid-May: the age of the smolt was of little concern. Under these conditions an average survival rate of 12% can be expected and can vary from 5% to 50%. Koenings and Burkett (1987) also suggest that smolt age has less to do with ocean survival than smolt size as increased size was correlated with increased survival for smolts up to about a 110 mm size.

Amend et al. suggest that since the age of sockeye salmon smolts at outmigration is not a factor for optimum marine survival, that it is most cost effective to release sockeye salmon smolts from the hatchery as underyearlings. This reduces labor costs and increases efficiency. Their approach has been to get the fish to optimum size by May of their first year by installing a heat exchanger using sea water as a heat sump to warm the freshwater. This allows more rapid development of eggs and fry during the cold winter months.

TIME AND LOCATION OF RELEASE

Traditionally, hatchery-reared salmonids are stocked in the spring to fit hatchery production schedules and to take advantage of favorable environmental conditions (Potter and Barton 1986). Smolt releases from anadromous fish hatcheries are usually timed to coincide with the outmigration of wild conspecifics, typically in the spring (Levings and Lauzier 1988). This likely results in greater survival by mimicking natural migration patterns. Concurrently, it also increases the risk of density-related mortality and undesirable interactions, even though presently there are few data on ecological interactions between hatchery and wild smolts (Steward and Bjornn 1990). Several studies have demonstrated that spring stocking of presmolts generally results in higher survival than fall stocking of presmolts (Fraser 1978; Strange and Kennedy 1979). However, because survival is jointly affected by stocking time and size, Hume and Parkinson (1988) were unable to identify an optimum time of release for underyearling steelhead trout.

Stocking times within the spring period only can greatly affect salmon and steelhead survival. It is possible to use release timing to manipulate the subsequent marine distribution (Irvine and Ward 1989) and timing of adult returns (Evans and Smith 1986). Delayed releases may speed downstream migrations of hatchery smolts (Zaugg et al. 1986), but may risk causing increased residualism, lower survival, and increased straying of returning adults if delayed for too long (Scholz et al, 1978). For example, salmonid smolts released into the Columbia and Snake rivers from upriver hatcheries after the spring runoff period may be subjected to increased turbine-related mortality at the dams, especially during low flow years. As flows decline, less water is available to spill over the dams and to transport fish downstream (Seidel et al. 1988). Also, a portion of hatchery fish released after peak runoff periods may fail to migrate or may have a protracted downstream migration lasting for weeks or months (Levings and Lauzier 1988). Conversely, Wagner (1968) suggests that early releases may be inappropriate. Adult returns from smolt-size steelhead trout yearlings stocked in February and March were much lower than returns from releases in late April which is the natural time of emigration. Hemmingsen et al. (1986) showed a similar reduction in survival when the release date of coho salmon was advanced from July to May.

ANALYSIS OF SUGGESTED RELEASE STRATEGIES

From the above survey of the supplementation literature, it is apparent that there are a number of risks associated with hatchery supplementation. These include genetic risks, reduced fish health due to hatchery practices, inability to precisely mimic conditions found in the wild, and the inability to determine the precise combination of release dates and fish size, etc. Increased stress levels and social inferiority created by the hatchery environment may increase fish susceptibility to disease following release into the wild (Ejike and Schreck 1980). Genetic risks include the loss of allelic diversity due to breeding practices and selective pressures associated with artificial culture. Given the generally poor results of hatchery supplementation on rebuilding wild and natural runs, it is critical that Snake River sockeye salmon recovery efforts (captive broodstock production) be limited to no more than one generation. This short-term manipulation would allow for natural processes associated with gene flow, mutation and recombination at the population level to maintain and restore genetic variability (Lovejoy 1977). The success of the captive broodstock efforts will also be contingent on creating survival improvements downstream from the nursery lakes in the mainstem Snake and Columbia rivers.

- While eggs have been used successfully in Alaska and BC, the use of fingerling through smolt life stages would be the most prudent until a better understanding of lake community dynamics is achieved and survival conditions for the young sockeye salmon can be improved. Numerous options for the release of juvenile sockeye salmon are available.

- Releasing sockeye salmon fry into the lakes in the spring for rearing would subject them to two major sources of mortality: predation from native and introduced species, and poor nutrition and poor growth rates due to the oligotrophic conditions in the Sawtooth Valley nursery lakes. However, human involvement is greatly reduced by direct plants.

- Releasing fingerlings into net pens placed in the nursery lake in spring is an attractive alternative and provides a number of benefits. It would provide a controlled environment protecting fish from predators which range from native and introduced trout to otters and birds. The juveniles could be fed an controlled diet - a real plus given the extremely low nutrient levels currently existing in the nursery lakes. It would also allow acclimation to the nursery lake. The juvenile salmon could be released in the fall prior to ice up and allowed to overwinter in the lake. Migration in the spring would be volitional, thus avoiding the problem of density dependent mortality caused by releasing thousands of smolts in a river system.

- Releasing presmolts in net pens for rearing through winter presents unacceptably high risks associated with maintaining the net pen through severe winter conditions. Options for dealing with icing and power failures would need to be explored in depth before risking the loss of any juvenile sockeye because of unforeseen weather related difficulties.

- Releasing presmolts into the nursery lake in the fall would provide the advantage over simply releasing fry into the lake since increased size should provide a survival advantage. However the presmolts would spend a longer period of time in the hatchery and will have had less time to acclimate to the nursery lake. Present forage conditions in the nutrient poor lake would not be as critical to maximizing in-lake fish production.

- Releasing smolts (age l+) into the lake in the spring provides the advantage of large smolt size. Again the smolts reared in the hatchery would be subjected to the disease and stress risks inherent in hatchery operations, and would have less time to acclimate to the lake. Assuming that size of the smolt is the key determinant of future survival then this option appears favorable. However, in addition to the increased stress risks, it is unknown what effect limited exposure of the fish to the nursery lake will have on homing and spawning site selection behaviors. The danger with this option lies in the assumption that greater fish size translates into greater adult returns. From the Alaska work reviewed there appears to be a point of diminishing return on fish survival as it relates to smolt size.

Caution should be exercised when using out-of-basin experiences as guideposts for establishing outplanting protocol because of the dissimilarity between the Snake River sockeye salmon and other sockeye salmon stocks. Since, however, numerous experiences have documented a favorable relationship between smolt size and survivorship, initially this should be the focus. Fall releases of presmolts gives us the greatest flexibility in this regard while still maintaining a semi-natural rearing component. Spring release of juveniles into net pens until fall also permits some control of smolt size while increasing fish exposure time to the nursery lake. We recommend the pursuit of several release strategies by the TOC with subsequent evaluation allowing for adaptive changes when warranted. With additional limnological and fish population information further guidance for direct lake releases will be available.

Following are the recommended sockeye salmon release protocols to be used until fish numbers are not limiting.

1) Net pen rear fingerlings from 3 gm to 9.5 gm during June to October of the year prior to outmigration, release 10 days prior to lake turn-over.

2) Rear fish to presmolt size at the Eagle facility. Place fish in net pens in the fall and feed for seven days. Release the fish into the lake in October.

<u>Evaluations Needed</u>

a) Monitor the success of outmigrants from both rearing strategies using PIT tag interrogations as fish leave the nursery lake.

b) Analyze feeding habits of predators and monitor accumulation of piscivores adjacent to net pens during summer and fall rearing periods.

c) Assess the respective run travel times and survival success of migrating fish reared under the two different strategies as they pass through the mainstem hydropower facilities.

Additional release strategies to be implemented and evaluated when juvenile numbers permit.

3) Post-fertilization "spring" fingerling releases directly into the nursery lake.

4) In-lake incubation of newly fertilized eggs.

5) Direct spring (May) releases of smolts following acclimation holding.

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PART II

Limnological and Fisheries Investigations of Sawtooth Valley Lakes with Respect to Potential Rehabilitation of Endangered Snake River Sockeye Salmon

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Annual report submitted to the Shoshone-Bannock Tribes

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TABLE OF CONTENTS

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EXECUTIVE SUMMARY

In 1992 we began a series of limnological investigations to assess the potential for releasing Snake River sockeye salmon *Oncorhychus nerka* into five lakes in the Sawtooth Valley of Idaho. These five lakes (Redfish, Alturas, Stanley, Pettit and Yellow Belly) served as the historical rearing environment for juvenile sockeye salmon. In this report we summarize the results of our investigations in three chapters covering 1) basic limnology, 2) nutrient addition experiments, and 3) fisheries investigations.

In Chapter 1 we report on the basic limnological condition of the five lakes. Temperature and oxygen conditions in each of the lakes were sufficient to support sockeye salmon. Low nutrient concentrations in each of the lakes resulted in low concentrations of chlorophyll, high Secchi disk transparency, and low light extinction coefficients compared to most lakes in North America. Highest concentrations of chlorophyll were often present in the hypolimnion of the lakes. The phytoplankton assemblage in each lake was composed of species and sizes of cells that would be grazable by crustacean zooplankton. The high light environment present in the lakes suggests that predation by piscivorous fishes would be an especially important component of survival of juvenile sockeye salmon. In spite of similar chlorophyll concentration and phytoplankton biomass, the lakes exhibited large variations in the biomass of crustacean zooplankton. Higher zooplankton biomasses were present in Pettit, Stanley and Yellow Belly compared to

Redfish and Alturas lakes. A simulation model indicated that lakes with higher densities of zooplankton would produce faster growing juvenile fish.

In Chapter 2 we describe the results of nutrient addition experiments, and conclude that additions of nitrogen and phosphorus would enhance phytoplankton populations in each lake throughout the period of this study (late May - mid-September). The addition of minor and micronutrients further enhanced phytoplankton biomass in some lakes on a few dates. Phytoplankton populations responded more rapidly to nutrient additions in July than in June or September. In general, the addition of zooplankton to the nutrient enhancement experiments indicated that grazing by zooplankton did not reduce the growth of phytoplankton populations under nutrient-enriched conditions.

In Chapter 3 we describe the results of hydroacoustic, mid-water trawl and gillnet sampling. Redfish and Alturas lakes contained the largest populations of 0. *nerka,* but this species was also present in Stanley and Pettit lakes. Densities of 0. *nerka* were highest in Stanley Lake. The depth distribution of pelagic fish differed among lakes and among periods of the day when fish were sampled. The number of potentially piscivorous fish caught in gillnets was highest in Alturas and Redfish and lowest in Stanley and Pettit lakes. The number of potential competitors was greatest in Pettit and Stanley lakes.

CHAPTER 1

Limnological conditions of Sawtooth Valley Lakes with respect to potential growth of juvenile Snake River Sockeye Salmon

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INTRODUCTION

In 1991 the National Marine Fisheries Service listed the Snake River stock of sockeye salmon *Oncorhynchus nerka* as endangered under the Endangered Species Act. These anadromus fish begin their lives in five high elevation lakes in the Sawtooth Valley of Idaho. After rearing in the lakes for a year, the sockeye smolt and begin their 900 mile migration to the Pacific Ocean via the Salmon, Snake and Columbia Rivers. After 2-3 years in the ocean, mature adults return to the rearing watersheds to spawn (Idaho Fish and Game 1992; Burgner 1992). Historically, returning adult sockeye salmon likely exceeded 10,000 fish (Evermann 1896, cited in Bjornn et al. 1968), and returned to at least five lakes in the Sawtooth Valley. As late as the 1950's numbers exceeding 4,000 were reported (Bjornn et al. 1968). Since that time the number of returning adults has declined such that only four individuals returned in August 1991. The decline of this stock is likely due to a combination of problems associated with passage through dams on the Columbia, Snake and Salmon River systems, commercial and recreational fishing pressure, and degradation of spawning and rearing habitats.

In the fall of 1991 we began an assessment of the rearing habitats for juvenile sockeye salmon in five Sawtooth Valley Lakes (Redfish, Alturas, Stanley, Pettit and Yellow Belly Lakes). We examined a variety of limnological conditions that could reflect on the ability of each of the lakes to support the growth and survival of juvenile sockeye salmon. The progeny from the four returning adult fish in 1991 comprises a captive broodstock for this endangered species unit. One of the goals of our research program was to compare the rearing environments of each of the five lakes to help fisheries managers evaluate strategies for releasing juveniles from the broodstock program back into the lakes.

To assess the potential rearing environments in each of the five lakes, we examined temperature, oxygen, and light conditions; and estimated the abundance, species and size composition, and spatial distribution of crustacean zooplankton food resources. Sockeye salmon are cold-water fishes that prefer temperatures less that 15°C and oxygen conditions greater than 5 mg L^{-1} (Brett 1983; Kyle et.al. 1988). They are visually feeding zooplanktivores vulnerable to a variety of piscivorous fishes (Burgner 1992).

Investigations in other systems where sockeye salmon runs have declined suggest that reductions in nutrient input to the rearing lakes can occur when large numbers of decaying carcasses from spawned adults no longer exist (Keonings and Burkett 1987). We believe this oligotrophication process may have occurred in the Sawtooth Valley lakes and so we have also measured concentrations of nutrients, phytoplankton and zooplankton, and the degree of nutrient limitation exhibited by phytoplankton in the five lakes.

In this paper we present data on seasonal changes in temperature, oxygen, light, chlorophyll and zooplankton conditions in the lakes. We then compare these limnological conditions among the lakes to assess the potential production of juvenile sockeye salmon in each, and use this comparison to suggest some management strategies to consider in attempts to design a recovery plan for this population. A companion paper (Gross et al., Chapter 2) describes the nutrient condition of the lakes and documents the response of the phytoplankton assemblages to nutrient enhancement.

METHODS

We designed a limnological sampling regime to characterize the five Sawtooth Valley Lakes: Redfish, Stanley, Pettit, Alturas, and Yellow Belly. Routine sampling began in May of 1992 and ended in October of 1992. Lakes were sampled 3-4 times in May and June and once every 10 days for the rest of the season. Temperature and oxygen conditions were measured in some of the lakes in April and November.

At the deep station in each lake, we sampled temperature, oxygen, and light profiles, chlorophyll concentrations, and phytoplankton and zooplankton populations. Chlorophyll and zooplankton samples were collected at 2 additional stations on each lake. The methodology used is described in greater detail below for each parameter measured.

Temperature and Oxygen

Vertical profiles of temperature and oxygen were taken at l-5 m intervals with a YSI Model 58 Dissolved Oxygen Meter. Periodically throughout the field season, the oxygen content of water from three depths was measured with the Winkler method to verify the accuracy of the YSI probe (APHA 1976). Seasonal isopleths of temperature and oxygen as a function of depth were calculated (Wilkinson 1988).

Light Extinction

Vertical profiles of light extinction were measured at the deep station using a submersible Li-Cor Model LI-188B photometer. Measurements were taken at 2 meter increments from the surface to 28 m deep or until 1% of surface light was reached. The extinction coefficient was then calculated as the slope of the regression of In (% surface intensity) against depth (Wetzel 1983).

Water transparency was also measured at the deep station with a 20-cm black and white Secchi disk and recorded as the mean of the depth where the Secchi disk disappeared and reappeared.

Chlorophyll and Phytoplankton

An integrated epilimnetic phytoplankton sample was collected at the deep station in each lake by lowering a weighted l/4" diameter Tygon tube 6 m into the water column and emptying the contents into a l-l bottle. A 125ml subsample was preserved in Lugol's solution and kept for future analysis. The remaining sample water was used for chlorophyll determination. On some dates we also collected metalimnetic and hypolimnetic samples with a Kemmerer water bottle for chlorophyll and taxonomic analyses.

For routine analyses of chlorophyll we filtered 50-ml aliquots on 0.45 um cellulose acetate membrane filters. On two dates we also fractionated the water sample by filtering with 0.1 urn, 1.0 um Nucleopore membrane filters and 30 um Nitex nylon screens to establish the relative chlorophyll content of different size fractions of phytoplankton. The filters were either temporarily frozen or placed directly into 6 ml of 100% methanol and extracted in the dark for 24-48 hr at room temperature. The extracts were then analyzed fluorometrically (Holm-Hansen and Riemann 1978) with a Turner model 111 fluorometer calibrated with standard chlorophyll a (Sigma). After the initial reading the samples were acidified with two drops of 1.0 N HCl, and reread to correct for phaeophytin.

We collected samples for algal enumeration and biomass estimates from the same O-6 m tube samples taken for chlorophyll analyses. Additional samples were occasionally taken in the metalimnion and hypolimnion to examine the change in species composition with depth. We preserved the samples in Lugol's solution and subsequently filtered a single 100 ml aliquot from each depth strata sampled on 0.45 uM cellulose acetate membrane filters at low vacuum pressures (0.3 atm.). The filters were then mounted in methacrylic resin following the procedure of Crumpton (1987). Cells were identified and counted at 400X-magnification in 50-100 fields that transversed the filter to take into account the tendency of cells to concentrate on the edge of the filters (Holmes 1962). The dimensions of a minimum of 10 individuals in each taxa were taken, and biovolumes subsequently calculated assuming the algae conformed to fixed geometric shapes.

Zooplankton

Six vertical zooplankton tows were collected on each date using a Wisconsin style zooplankton net measuring 35 cm in diameter and 80 cm long with 80 um mesh. A General Oceanics flow meter modified to prevent reverse flow was used to determine net efficiency and volume sampled. Zooplankton were sampled over 2 depth ranges, a 10 meter to surface tow and a bottom to surface tow, at each of the three stations. The net was rinsed and zooplankton were preserved in 10% neutralized formalin solution. Revolutions per tow were recorded and densities were corrected for net efficiency and volume sampled. The zooplankton taxa identified included five cladocera *(Daphnia rosea, Bosmina longirostris, Holopedium gibberum, Polyphemus pediculus),* one calanoid copepod (Epischura nevadensis) and at least two species of cyclopoid copepods. In this report we refer to each species by genus. Zooplankton were enumerated and measured in replicated l-5 mL subsamples taken with a Hensen-Stempel pipette and placed in a circular counting dish. Individual lengths of each species were measured from each sample and mean length for each taxa was calculated. Biomass was determined for each species using the procedures and linear regression equations described by McCauley (1984) and Koenings et. al. (1987).

In addition to our routine zooplankton sampling, mid-summer vertical distribution and die1 migration of zooplankton was examined in Redfish and Stanley Lakes by collecting depth-stratified zooplankton tows during day and night periods. Zooplankton were collected using a closing net equipped with a flow meter. Samples were collected from Redfish Lake between 11:OO - 12:30 on August 3 and between 0:OO and 1:20 on August 4. Two replicate samples were collected from each 5-m depth strata from 0 - 20 m, each 10-m strata from 20 - 40 m, and each 20-m strata from

40 - 80 m. Two samples were collected from the bottom - 80 m. Samples were collected from Stanley Lake between 14:50 - 15:30 on August 2 and between 0:OO - 0:45 on August 3. Two replicate samples were collected from each 5-m depth strata from the bottom to the surface. Density of each crustacean taxa were estimated according to the methods cited above.

Lake Morphometry

We used an echosounder linked with a global positioning system (GPS) to chart the bathymetry of each lake in October 1992 using the methodology of Gubala et al. (in press). Depth data from an American Pioneer Fishscope II echosounder (6.5° beam angle, I60 kHz), and position data from a Trimble Pathfinder Professional GPS unit were recorded on a data logger at a-second intervals as our boat cruised at 2-4 m/s along transects in each lake (paths shown in Appendix 2). For the different lakes we recorded between 860 and 1540 depth and position points, depending on their size. Because the Department of Defense degrades the satellite-transmitted GPS data through Selective Availability, uncorrected location measurements can be up to 100 m in error. Consequently, we corrected our position data by recording deviations a of GPS unit fixed at the Sawtooth National Fish Hatchery which is within 24 km from the furthest lake. The GPS positions recorded in the boat were then differentially corrected for these deviations with Asset Survey software of Trible Navigation, Ltd. giving a final accuracy of approximately + 5 m. In addition to the GPS locations, we added 160-570 points for the perimeters of the lakes by digitizing USGS topographic maps (7.5' series). Because we did our survey in October at the end of the hydrologic year during a six-year drought, we increased each of our depth readings by 0.5 m to more closely represent normal water conditions in the lakes.

Morphometric maps and depth-area curves were generated with the software program SURFER using griding patterns of approximately 100 x 90. Lake surface areas generated by the program averaged 94% (range, 90-97%) of the surface area estimated by digitizing the USGS maps. The reason for this difference is not known.

RESULTS

Morphometric characteristics of the five lakes are described in Table 1 and the lake basins are shown in Figure 1 and Appendix 1. Hypsographic and depth-volume curves are given in Appendix 3.

Table 1 .Morphological characteristics of the five lakes.

LAKE	AREA (KM^2)	VOLUME (m^3x10^6)	DEPTH MAX (m)	DEPTH MEAN (m)
Redfish	6.15	269.9	91	44
Alturas	3.38	108.2	53	32
Pettit	1.62	45.0	52	28
Yellow Belly	. 73	10.3	26	14
Stanley	.81	10.4	26	13

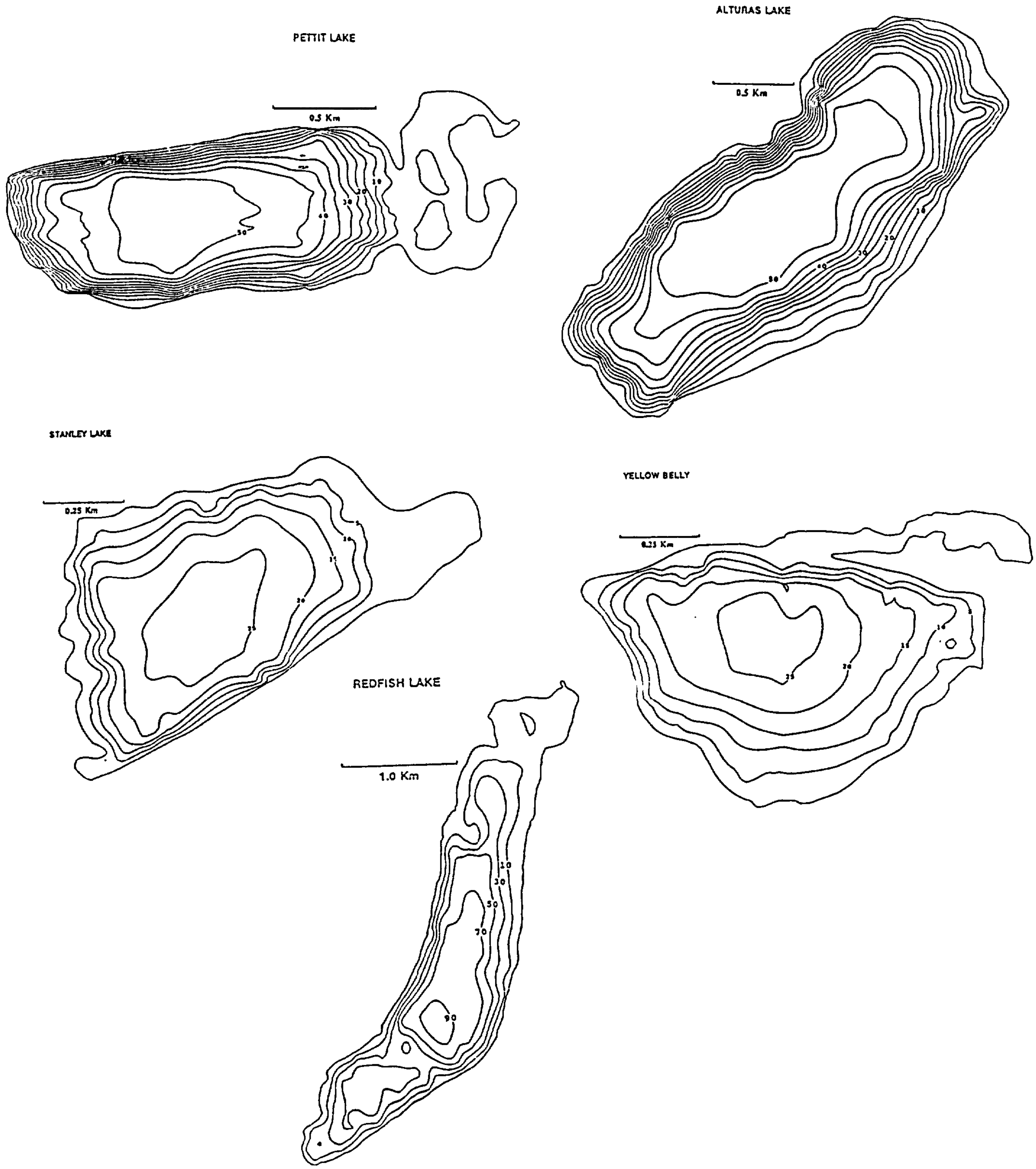


Figure 1. Morphometric maps with depth contours in meters for each lake.

Temperature and Oxygen

Seasonal temperature and oxygen data measured by the YSI probe are summarized in Figure 2 (a-e). The YSI readings varied within O-16% of the Winkler measurements when comparing both different depths and lakes.

Seasonal development of thermal stratification was similar in each of the lakes. Temperatures ranged from maximum surface temperatures of 18^0C to 4^0C at depth over the 8 months sampled. Surface temperatures reached a high of 18 degrees C only for a short period in late July and early August and remained between 12-16 degrees for the majority of the summer. The thermocline developed in mid-May and was generally located between 8 m and 18 m in the deeper lakes (Redfish, Alturas, and Pettit) and between 8 m and 15 m in the shallower lakes (Stanley and Yellow Belly).

Dissolved oxygen levels in mid-May ranged from 4 mg/L at depth to 10 mg/L near the surface of all lakes (Figure 2). As thermal stratification evolved oxygen concentrations were reduced in the hypolimnions of all the lakes. Low levels of dissolved 0, (< 3 mg/L) were measured at depth in all lakes except Redfish. The low oxygen levels were located a few meters off the bottom in Alturas (45-50 m),Stanley (22-25 m), and Yellow Belly (21-25 m) but were found as shallow as 40 m in Pettit Lake. Pettit, Stanley and Yellow Belly Lakes exhibited prolonged periods where the bottom water remained below 2 mg 0, / L.

A metalimnetic oxygen maxima of approximately 10 mg/L dissolved oxygen developed in Alturas, Yellow Belly, Pettit and

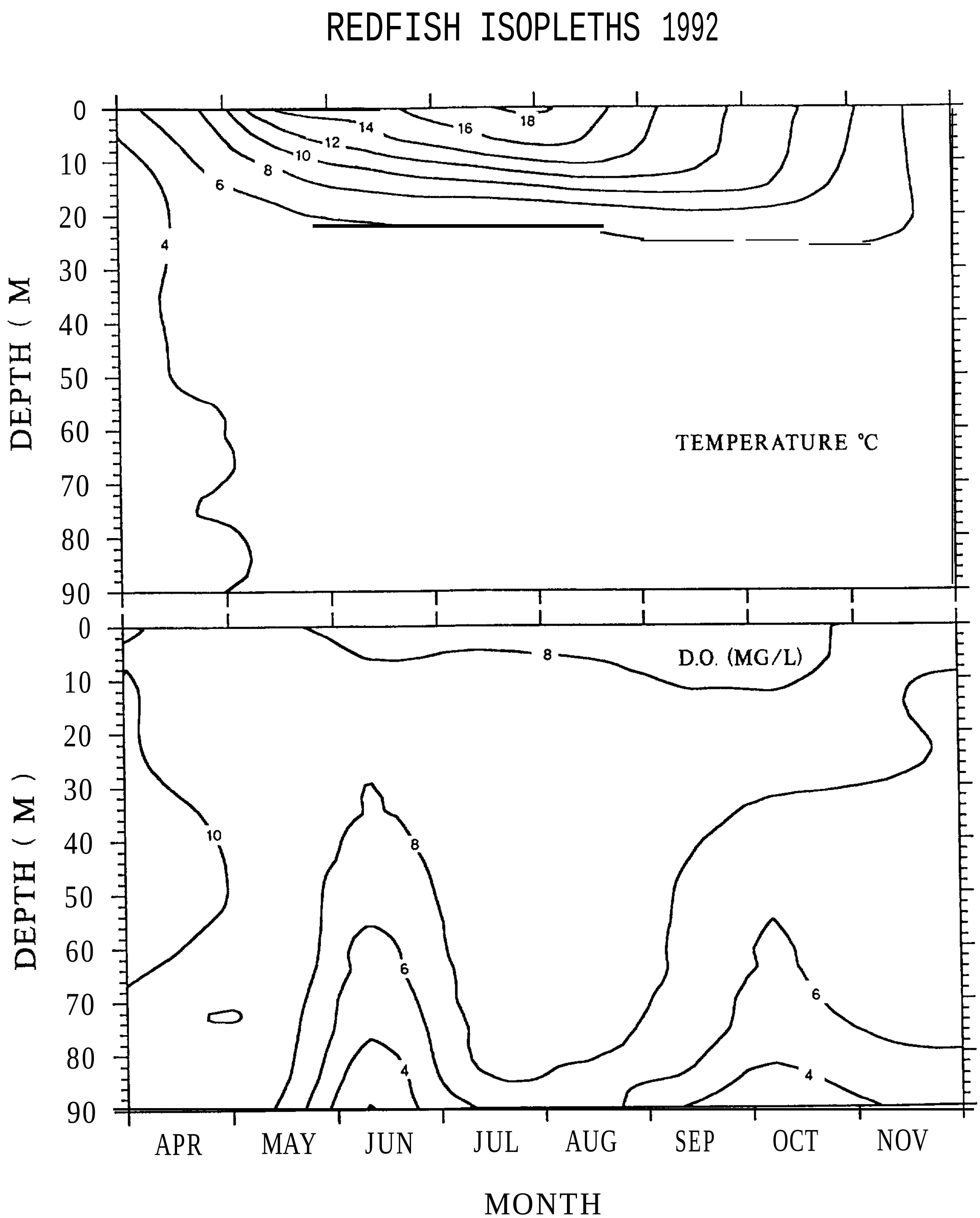
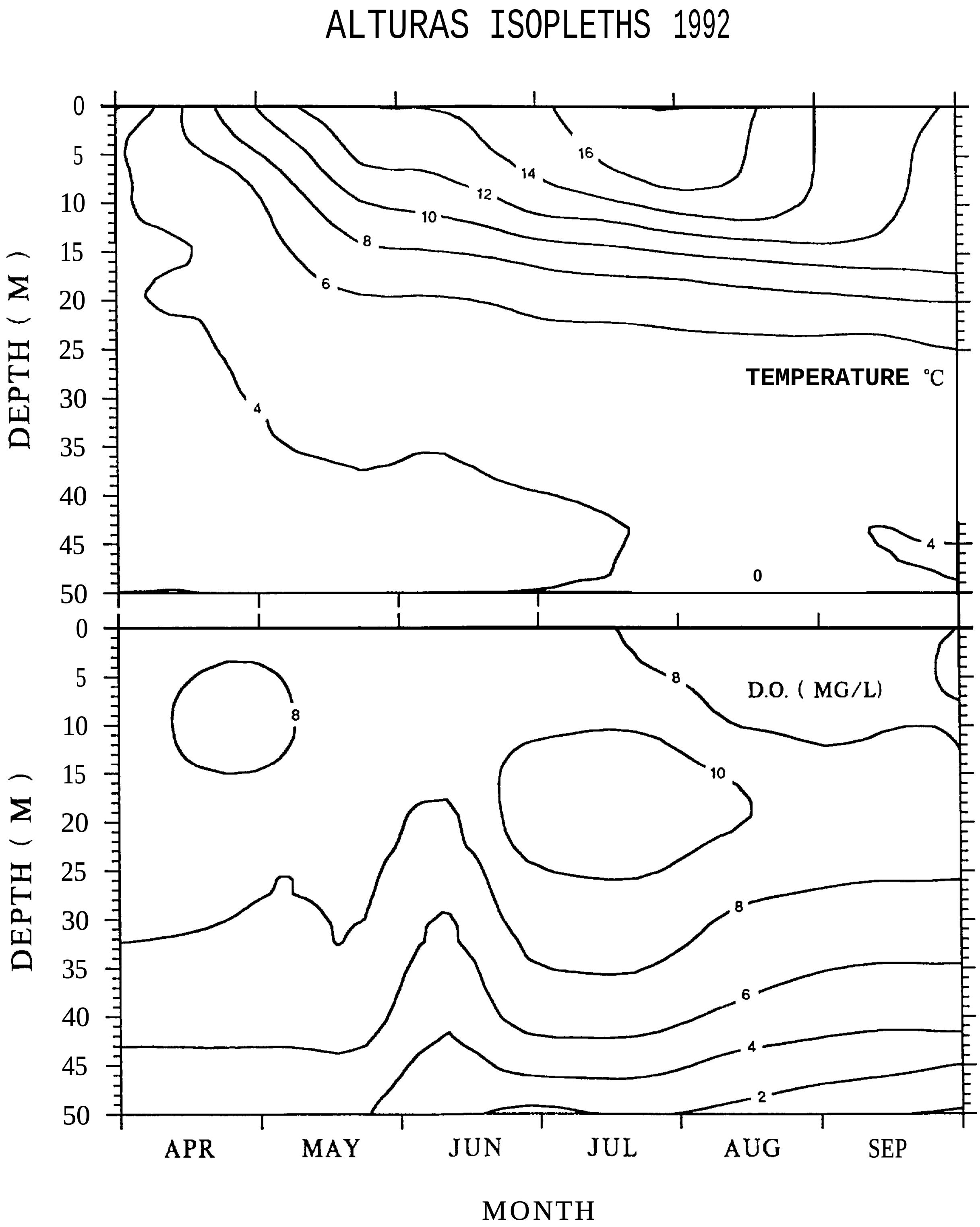


Figure 2. Temperature and oxygen isopleths for each lake.
a) Redfish b) Alturas c) Pettit d) Stanley e) Yellow Belly



ALTURAS ISOPLETHS 1992
DEPTH (M)
TEMPERATURE °C
D.O. (MG/L)
APR
MAY
JUN
JUL
AUG
SEP
MONTH

Figure 2. b.

PETTIT ISOPLETHS 1992

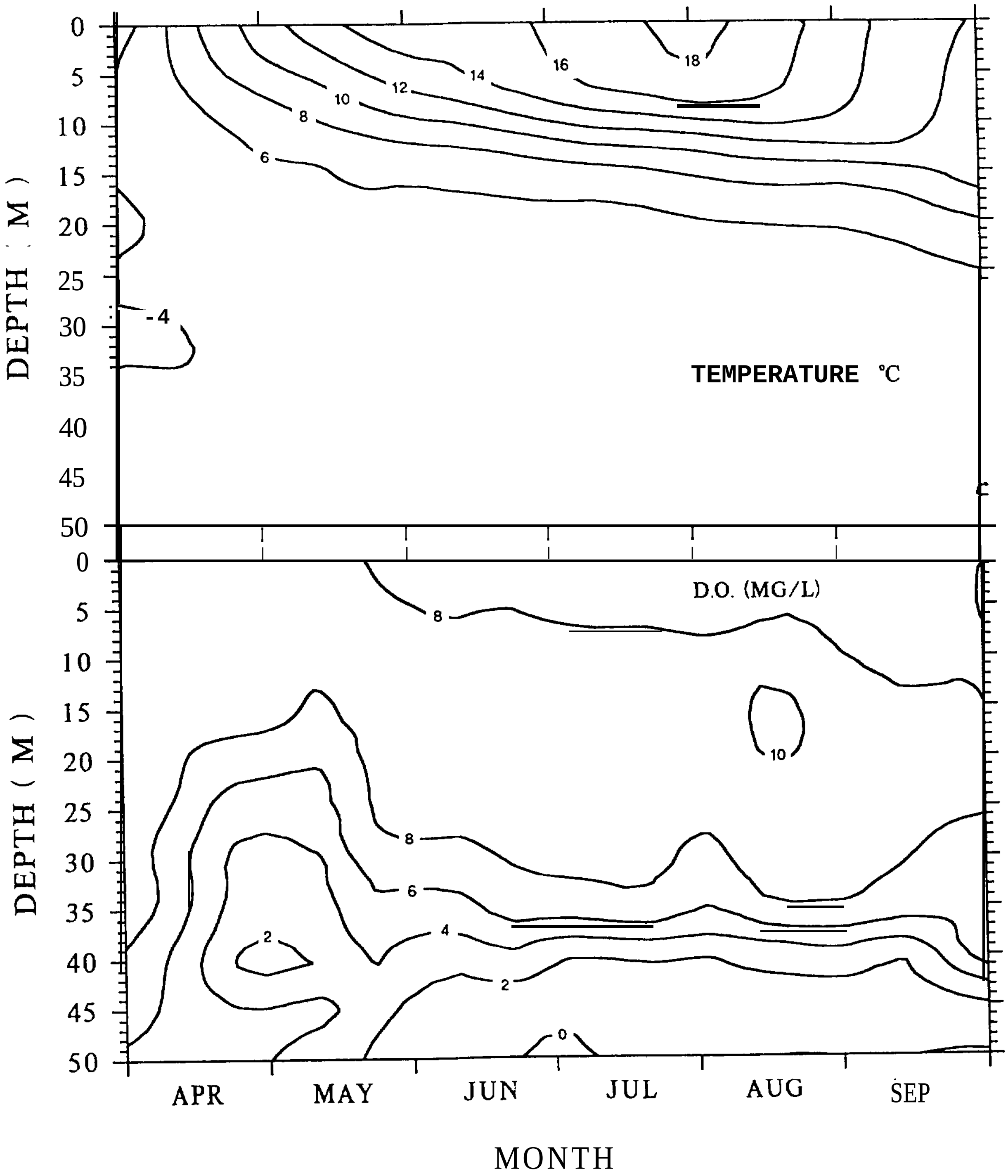


Figure 2. c.

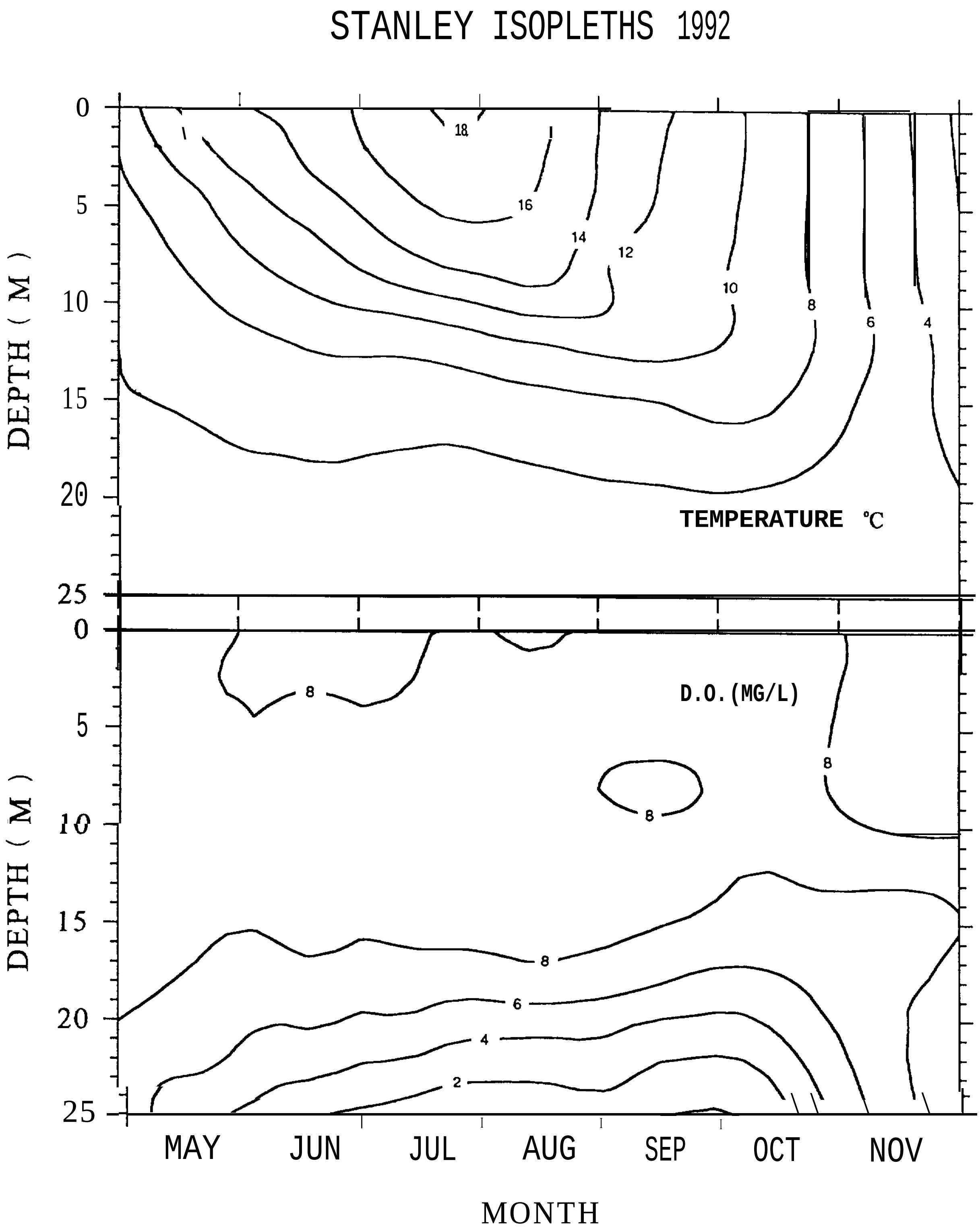

STANLEY ISOPLETHS 1992
DEPTH (M)
0
5
10
15
20
25
18
16
14
12
10
8
6
4
TEMPERATURE ℃
D.O.(MG/L)
8
6
4
2
MAY
JUN
JUL
AUG
SEP
OCT
NOV
MONTH

Figure 2. d.

YELLOWBELLY ISOPLETHS 1992

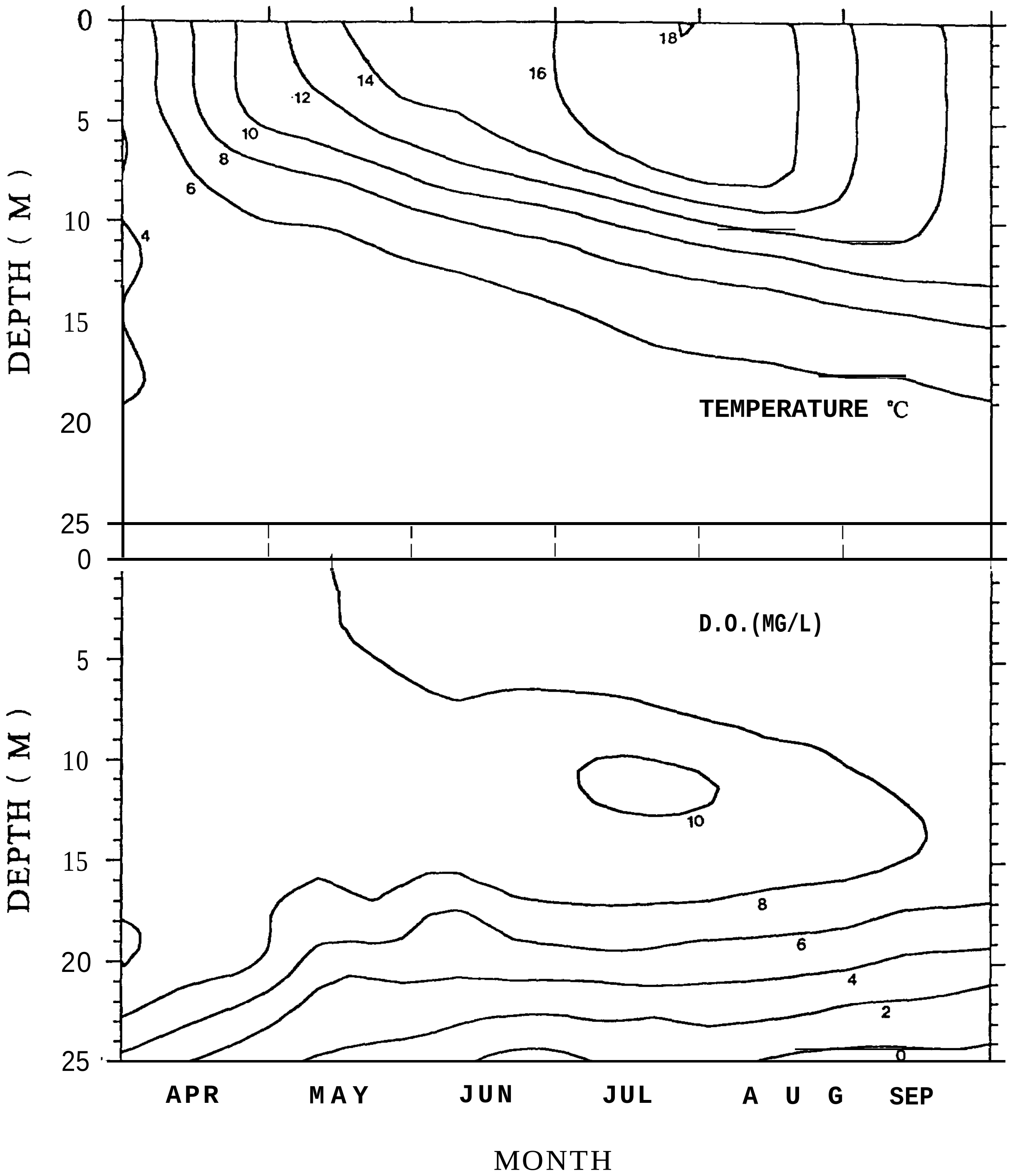


Figure 2. e.

Stanley lakes in mid-summer. This maxima lasted for as short as 12 days (Pettit) and as long as 2 months (Alturas). Redfish Lake did not develop a distinct maxima.

The 1% light extinction depth was generally 1.5 - 2 times the Secchi depth in each lake. The relationship between the 1% light level and the Secchi depth was linear when data for all five lakes was combined (Figure 3). The relationship was much tighter if light extinction and Secchi were examined for each lake individually.

The seasonal distribution of secchi depths for all five lakes exhibited the same general trend (Figure 4). Secchi transparency gradually decreased from May to September and then showed a slight increase in October. Stanley lake had much lower Secchi transparencies throughout the season compared to the other lakes.

The average epilimnetic chlorophylls from May 9 to November 18 for the five lakes ranged from 0.44 to 0.90 mg/m^3, with values ranging from 0.22-2.38 mg/m^3. The highest epilimnetic chlorophyll value for each lake occurred on May 9, when the first measurements were taken (Figure 5) approximately 2 weeks after spring overturn. The minimum epilimnetic chlorophyll value for each lake occurred between July 10 and August 10. Epilimnetic chlorophyll values increased during autumn as the thermocline began to erode.

Chlorophyll a depth profiles were measured for 3 lakes (Alturas, Redfish, and Stanley) between July 25 and August 1 and for all 5 lakes between September 14 and 18, 1992 (Figure 6). Each lake revealed a deep chlorophyll maximum at an average of 1.9

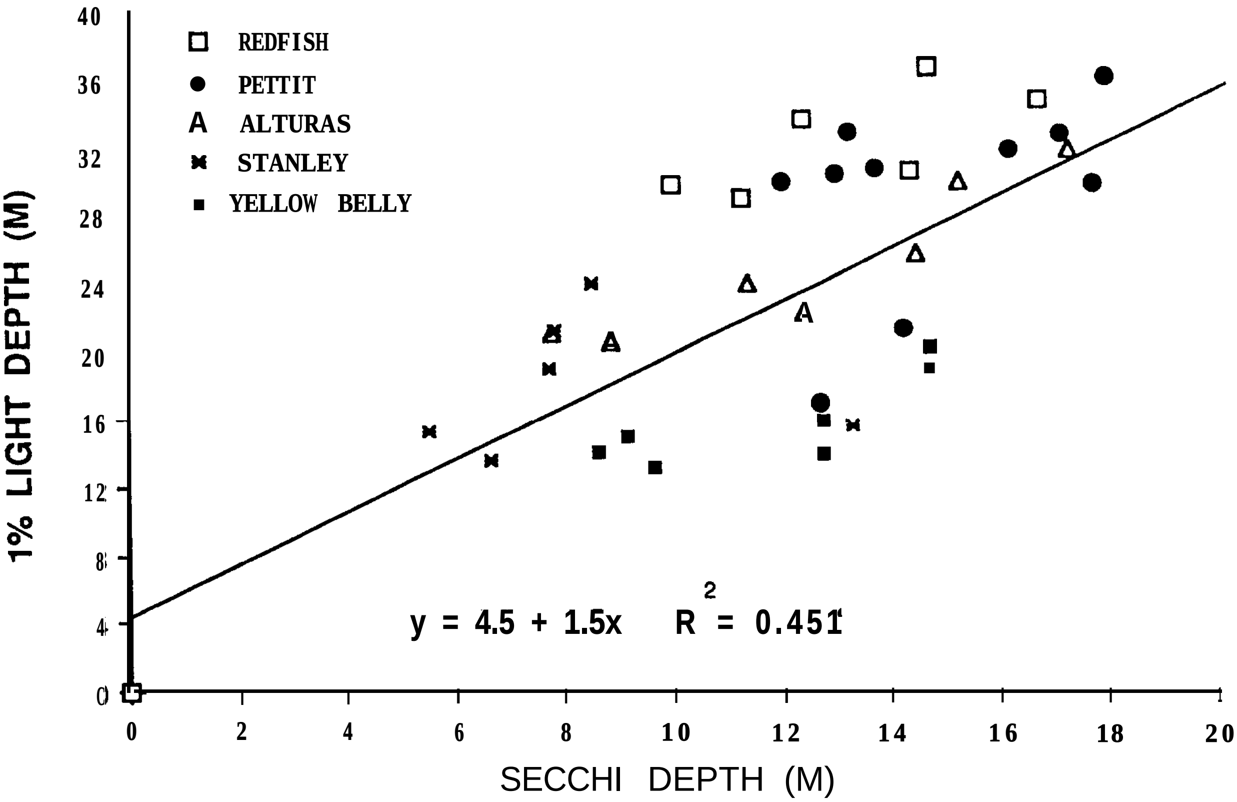


Figure 3. Depth of 1% light extinction versus secchi depth in all five lakes.

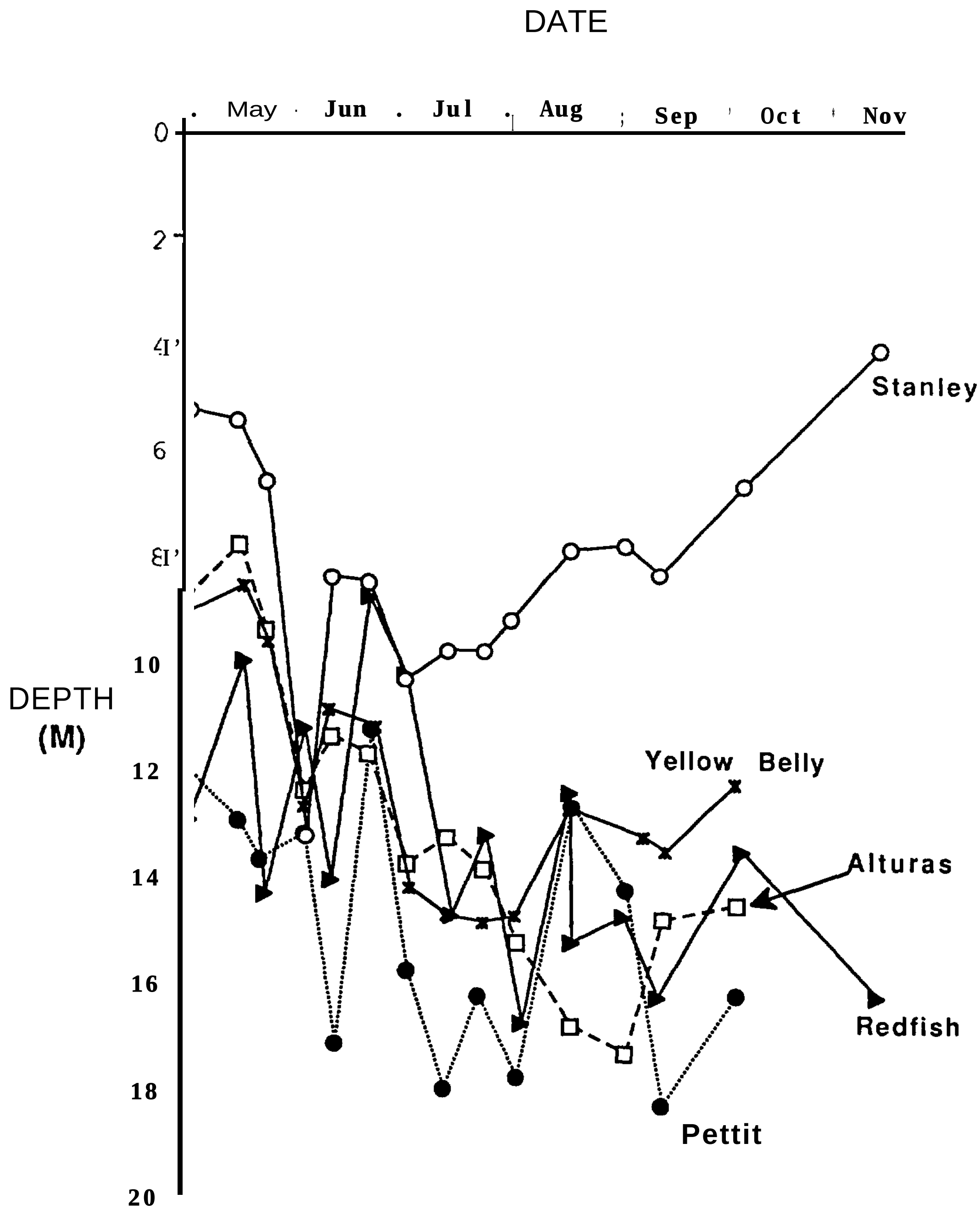


Figure 4. Seasonal distribution of secchi depths for all five lakes.

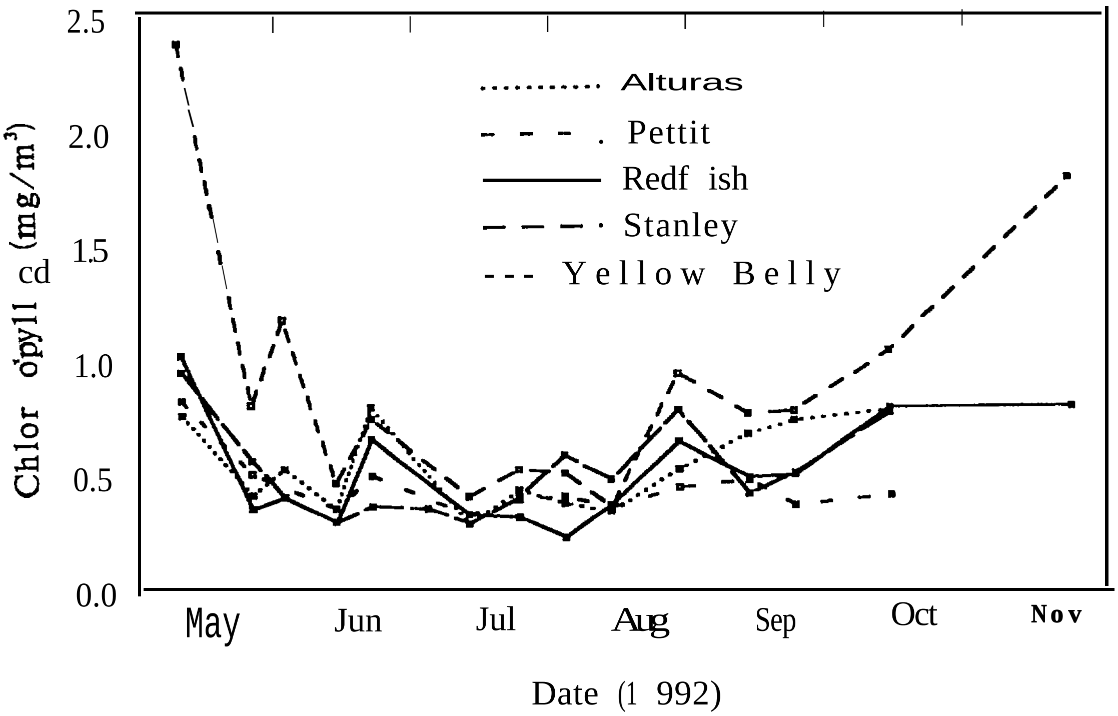


Figure 5. Seasonal distribution of mean chlorophyll *a* levels for all five lakes.

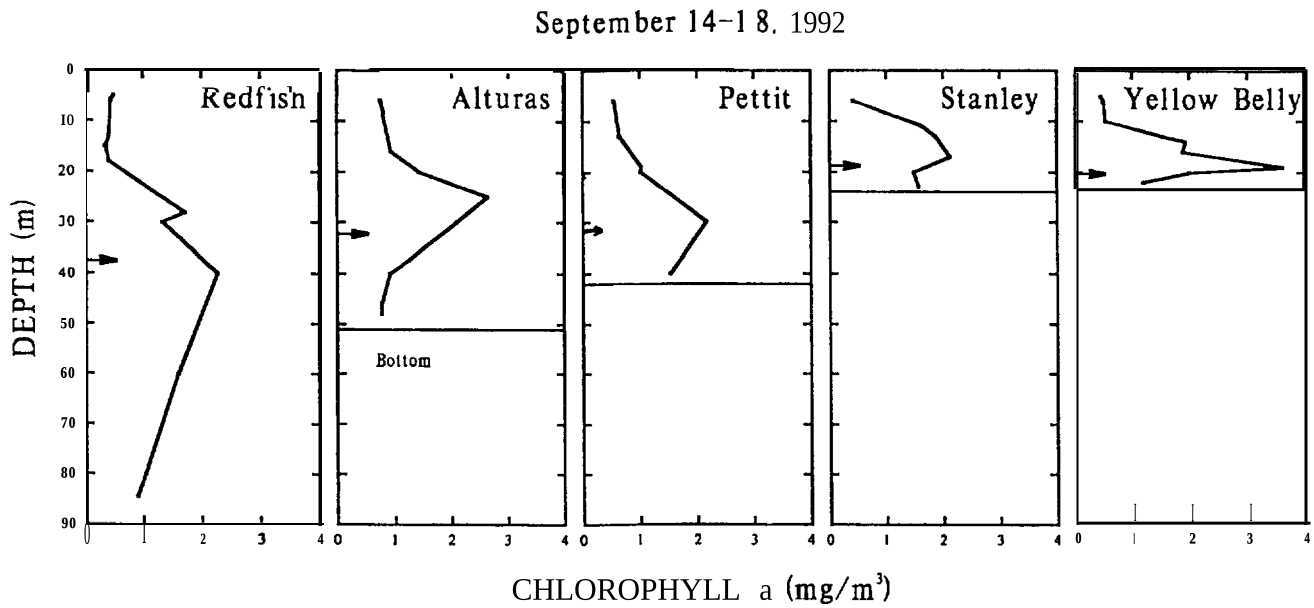


Figure 6. Chlorophyll a profiles for each lake. The arrow represents the 1% light extinction depth.

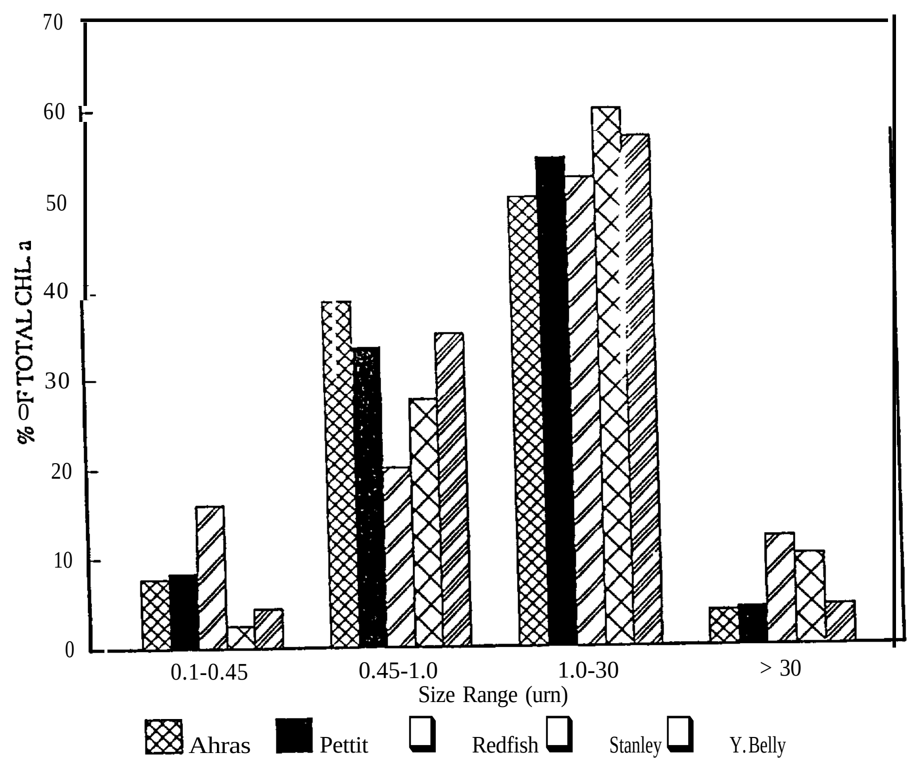
secchi depths (SE = O.l) where the mean temperature was 5.4 °C (SE = 0.3). The deep chlorophyll maxima were all located 9.8 m (SE = 1.9) below the peak in the oxygen profile.

The size-fractionation analysis of epilimnetic water revealed a similar size distribution of phytoplankton in each of the five lakes (Figure 7a). Seventy-two to 91% of the chlorophyll in the five lakes was distributed in grazable size classes (0.45 - 30 urn, Reynolds 1984). Only 4 to 12% of the phytoplankton in the five lakes was larger than 30 urn. In Redfish Lake, size-fractionation analysis of samples collected at four depths (O-6 m, 14 m, 35 m, and 80 m) indicated that 60 and 82% of the phytoplankton at each depth was grazable (Figure 7b).

The phytoplankton taxa, exemplified by those in Redfish Lake, was dominated by the following taxa:

TAXONOMIC GROUP	MEAN VOLUME (uM^3)	EQUIV. SPHERICAL DIAMETER (uM^3)
Yellow-brown Algae		
Dinobryon sp.	1226	13.0
Diatoms	1067	12.4
Green Algae		
Chlorococcales	51	4.6
Chlamydomonas	907	11.8
Cyanobacteria (BGA)	55	4.7

a.



b.

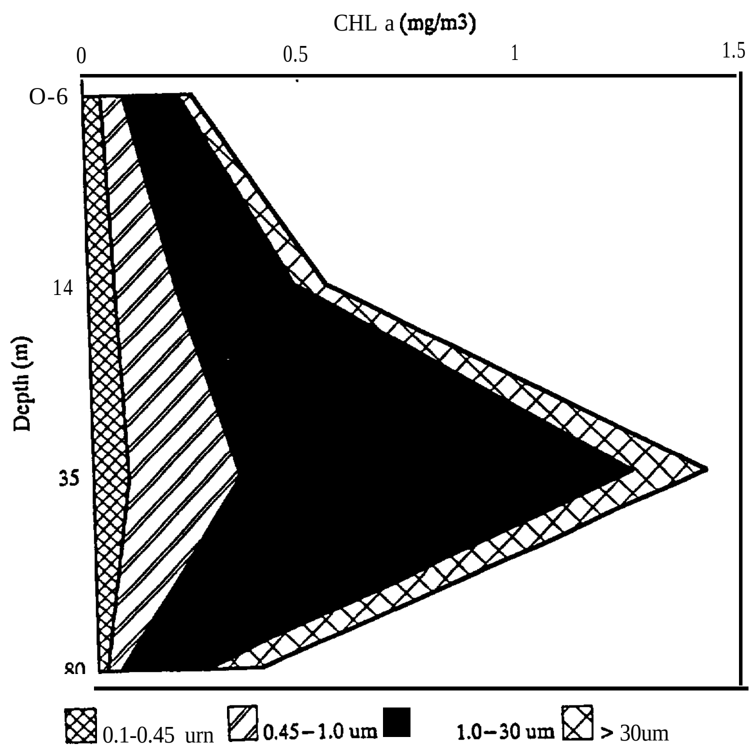


Figure 7. a) Phytoplankton size fractionation in relation to the percentage of total chl a for all five lakes; O-6 m sample, 9-11 July, 1992. b) Depth stratified phytoplankton size fractionation for Redfish Lake, 9 July, 1992.

Nearly all of the phytoplankton were small, and the mean equivalent spherical diameters for all of the taxa ranged from about 4 to 12 uM.

In the epilimnion of Redfish Lake the algal biomass was moderately high from April to May, with a peak in the last two weeks of June (Figure 8). During the spring the community was dominated by *Dinobryon* sp., very small unidentified spherical green algas of the order chlorococcales, and diatoms (principally *Cyclotella sp. , Tabellaria* sp., and *Fragillaria* sp.). In early July the algal biovolume plunged an order of magnitude from the spring high, and became dominated by small cyanobacteria and *Dinobryon* until the end of August when diatoms and the green algae *Chlamydomonas* sp. became appeared.

Seasonal shifts in algal biovolumes in Alturas, Pettit and Yellow Belly Lakes were erratic, but showed patterns similar to that in Redfish Lake, with much higher volumes in the spring, and falling to lower levels by June or July (Figure 9). Estimated biovolumes in Stanley Lake were also erratic, but appeared to be relatively constant throughout the year.

Mean biovolumes (April-August) of phytoplankton in the five lakes were:

Lake	uM^3/ml
Redfish	27,400
Alturas	79,700
Pettit	46,400

Stanley	36,500
Yellow Belly	88,200

Algal biovolume was lowest in Redfish Lake, and highest in Yellow Belly Lake. Surprisingly, the biovolume in Stanley Lake was the second lowest. The mean biomass shown for Alturas Lake lacks data from some early spring samples that appeared erroneous (Figure 9). These samples are currently being recounted.

The phytoplankton in the deeper waters of Redfish Lake were more abundant and had a different taxonomic composition than those in the epilimnion. In July (Figure lo) the epilimnetic biovolume was dominated by cyanobacteria *(78%)*, *Dinobryon* (lo%), and diatoms (8%). At the top of the metalimnion (14 m), algal biovolume increased slightly due to an increase in *Dinobryon* sp. In the hypolimnion (80 m), the total biovolume was nearly nine times greater than in the epilimnion and was dominated by diatoms. The much greater biovolume of the diatoms undoubtedly contributed to the 2x increase in chlorophyll *a* concentrations with increasing depth that was measured on this date. In August (Figure 10) the epilimnion community was composed of diatoms (38% by volume), *Chlamydomonas* sp. (48%) and small chlorococcales (11%). *Chlamydomonas* sp. disappeared in the upper metalimnion (14 m), as diatoms increased to represent 89% of the community. Near the peak of the deep chlorophyll maxima (35 m), the biovolume was nearly eight times higher than in the epilimnion, and the diatoms *Asterionella* sp., *Synedra* sp., and *Cyclotella* sp. represented 99%

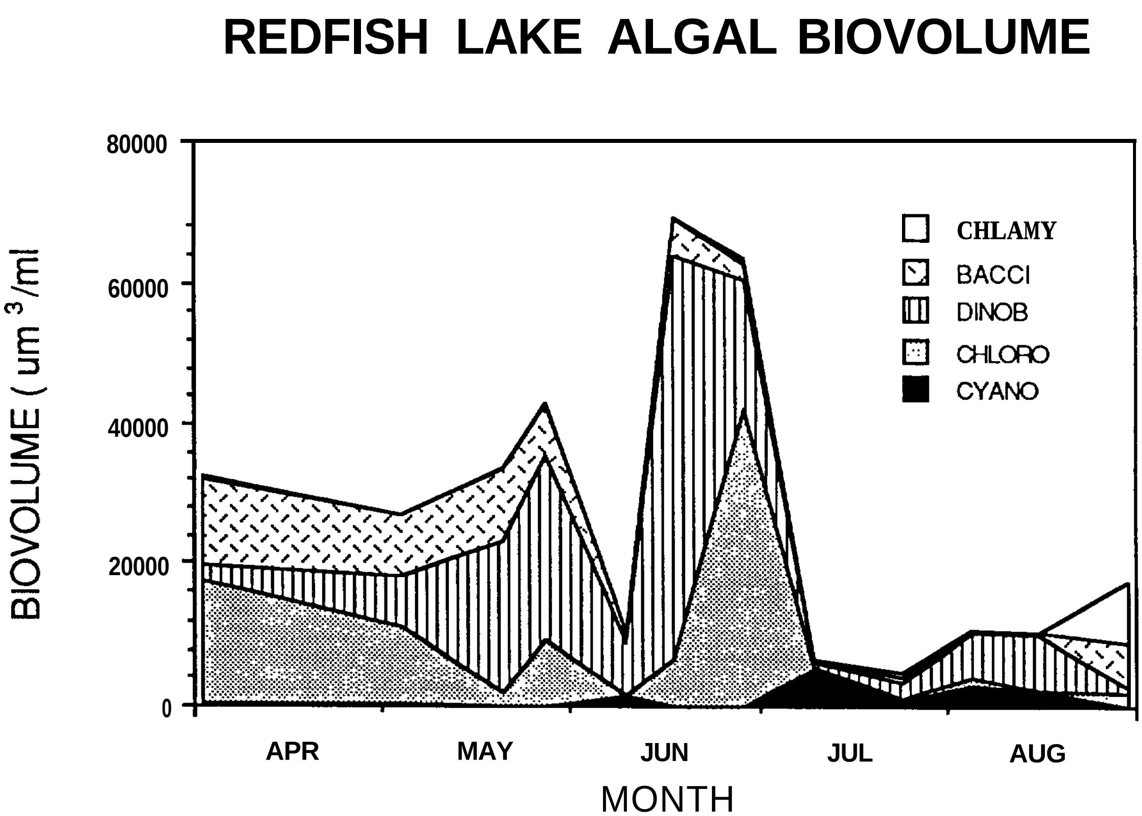


Figure 8. Seasonal changes in the biovolume of different phytoplankton taxa in the epilimnetic water of Redfish Lake, 1992.

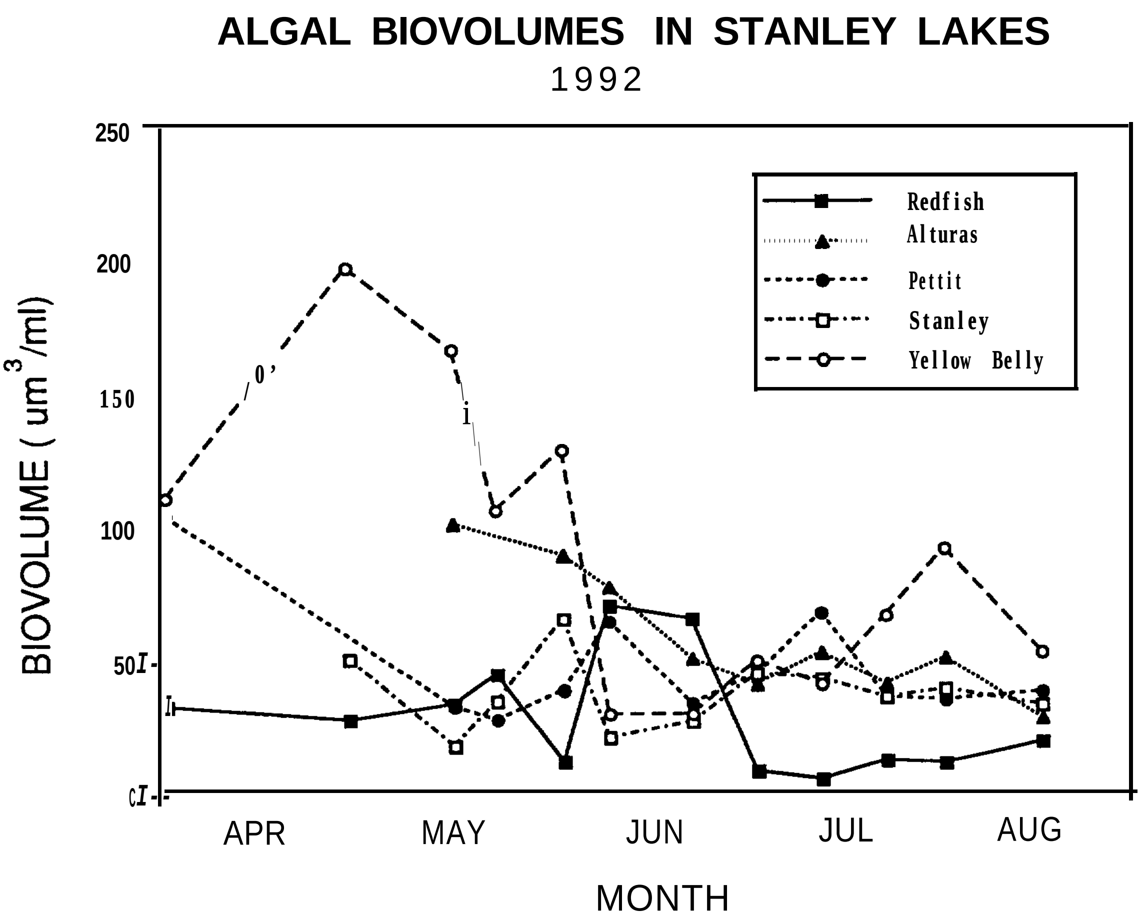


Figure 9. Seasonal changes in total epilimnetic algal biovolume in the five lakes, 1992.

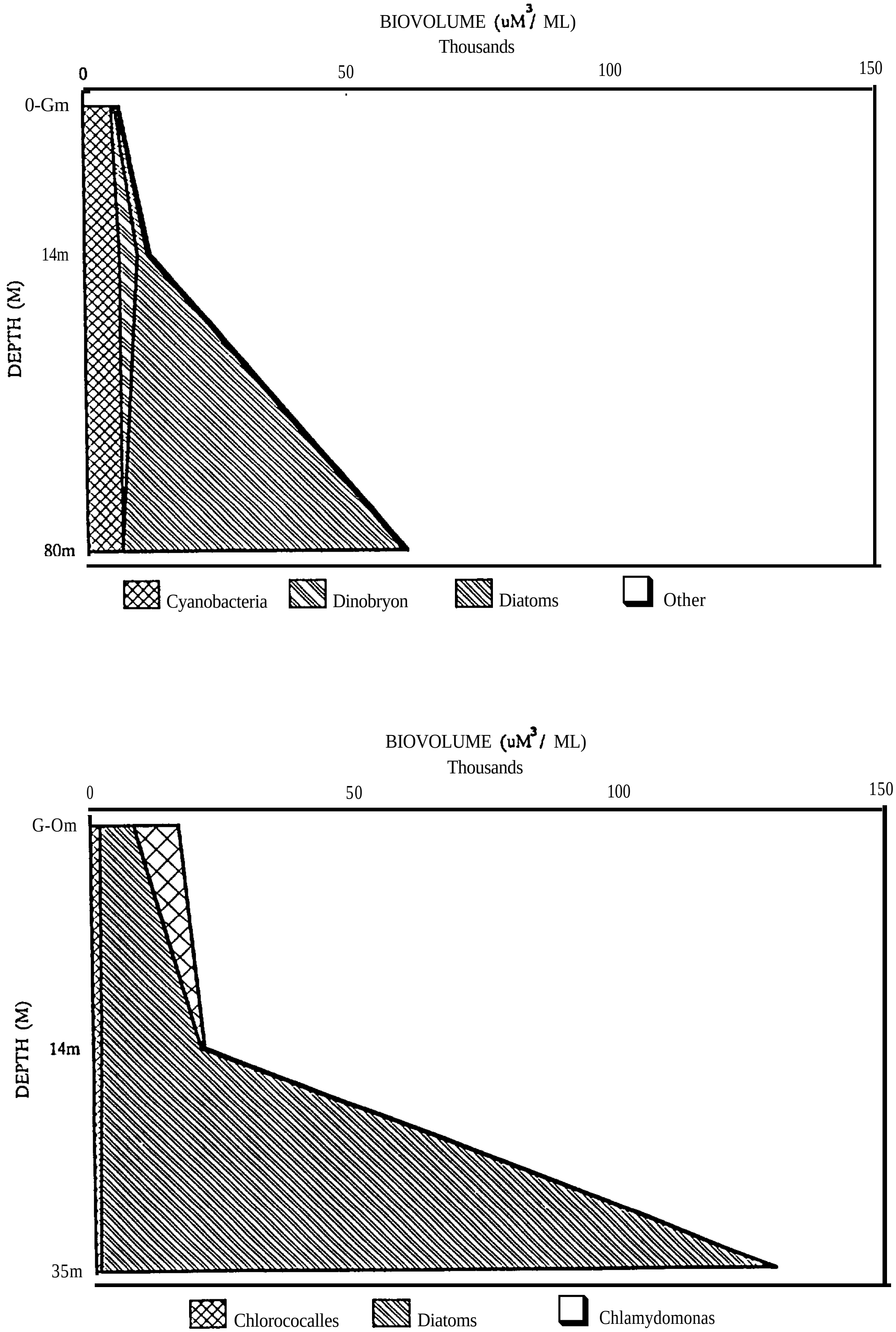


Figure 10. Changes in algal taxanomic composition with depth in Redfish Lake. 9 July 1992 above; 24 August 1992 below.

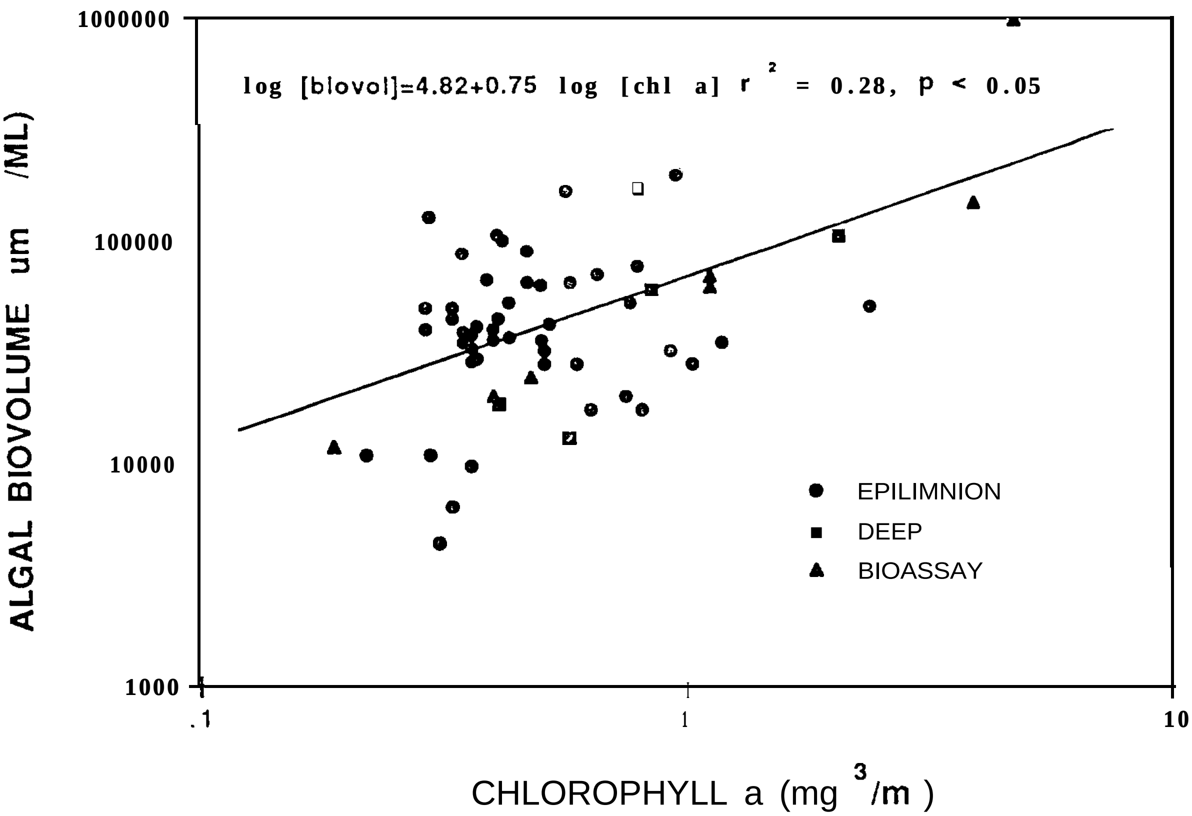
of the biovolume.

There was a reasonably strong relationship between measured biovolumes and the concentration of chlorophyll *a in our* samples (Figure 11). At biovolumes near 10,000 uM^3/ml, chlorophyll *a* concentrations were 0.2-0.4 mg/m^3, whereas at biovolumes near 100,000 uM^3/ml, chlorophyll concentrations were between 1 and 3 mg/m^3. Nevertheless, there was considerable scatter in the relationship, suggesting that chlorophyll concentrations provide only a rough approximation of algal biomass at any one point in time.

The seasonal distribution of epilimnetic (10-o m) zooplankton biomass for each species is presented in Figure 12 for each lake. The same species were found in all five lakes with the exception of Stanley, which was the only lake containing *Epischura nevadensis.* Biomasses, densities, and seasonal successional patterns varied considerably among lakes.

Redfish and Alturas exhibited (Figure 12a,b) the lowest biomass of all species *(<25* ug/L) with *Holopedium* dominating most of the season in Redfish and Bosmina dominating in Alturas. A sharp decline in total cladoceran biomass occurred in both these lakes in mid-summer. The carnivorous cladoceran Polyphemus exhibited a substantial increase in Alturas immediately after the sharp decline of both *Bosmina* and *Holopedium.* Neither of these two lakes had abundant populations of *Daphnia* or copepods in the epilimnion.

Pettit, Stanley, and Yellow Belly lakes all had much higher



NOTE IN PRESS - ERRORS HAVE BEEN FOUND IN THE CALCULATION OF ALGAL BIOVOLUME FROM THESE SAMPLES. AN AMENDED FIGURE WILL BE FORTHCOMING.

Figure 11. Relationship between chlorophyll a and bio-volumes of phytoplankton during the summer. Shown are points from the epilimnion, metalimnion, and hypolimnion, as well as a **limited** number of points from nutrient-enriched bioassay treatments.

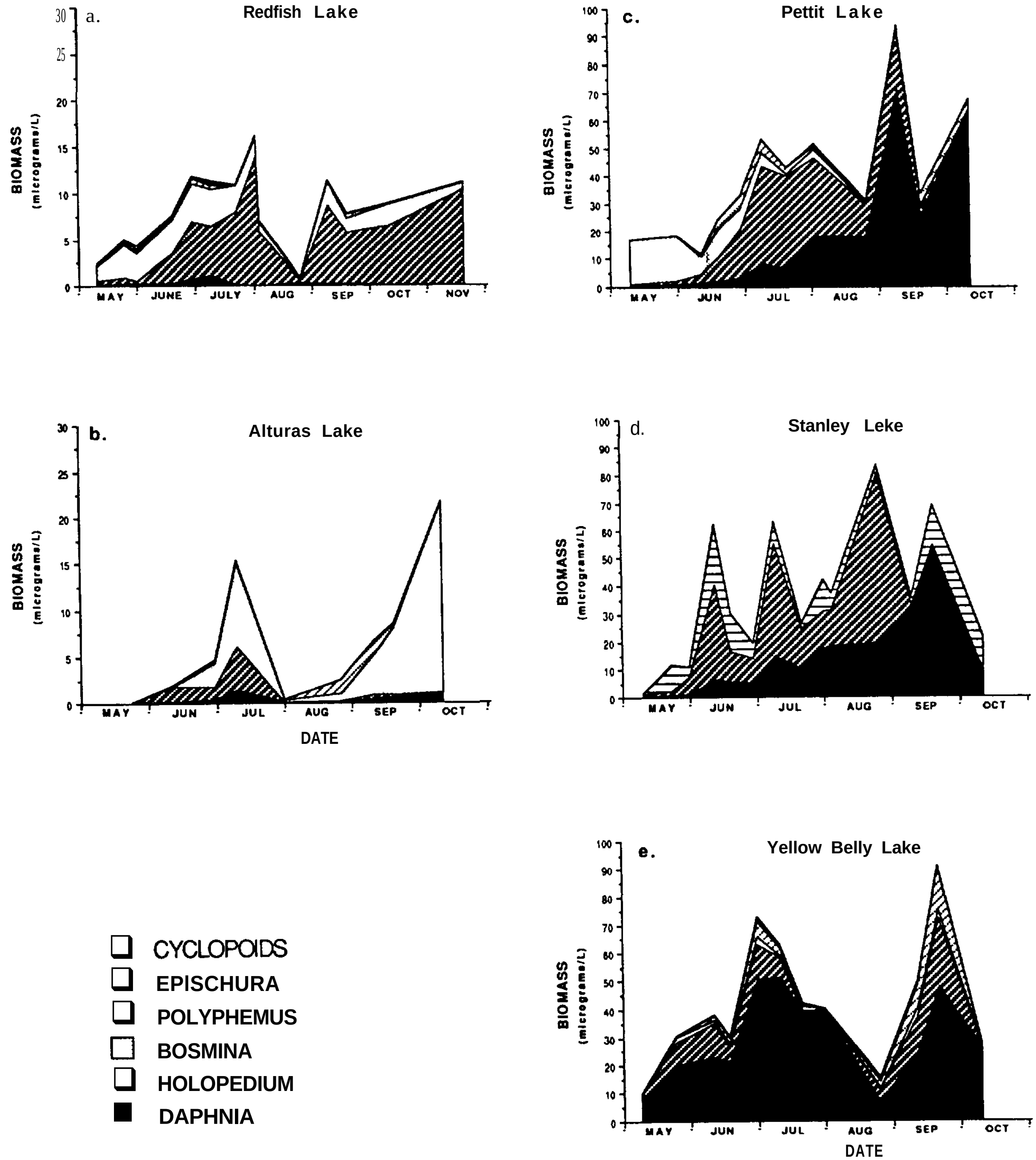


Figure 12. (a-e). Seasonal distribution of zooplankton biomass for all five lakes.

cladoceran densities than Alturas or Redfish. Pettit exhibited a distinct seasonal succession of cladoceran species in which Bosmina had the highest biomass from May through mid-June, *Holopedium* dominated in July and August, and *Daphnia* dominated during September and October. *Daphnia* dominated the zooplankton of Yellow Belly throughout the year, but also exhibited a mid-summer decline in crustacean biomass.

Zooplankton densities estimated from bottom to surface tows were generally lower than values estimated in the epilimnion (Figure 13). Cyclopoid copepods were much more abundant in the hypolimnion in each of the lakes. *Holopedium* and *Epischura* were much more abundant in the epilimnion. Densities of *Bosmina* and *Daphnia* were similar in epilimnetic and whole water column tows. Whole water column tows over-emphasize zooplankton taxa that occurred in the hypolimnion in that the efficiency of the net decreased with length of tow.

Seasonal distribution of total zooplankton densities and biomasses indicated that Redfish and Alturas contained the lowest biomass of crustacean zooplankton through the season compared to the other lakes (Figure 14). Pettit had a high density but low biomass of total zooplankton early in the season owing to the dominance of small-bodied *Bosmina.* The dominance of Bosmina in Alturas throughout the season resulted in high -densities of total zooplankton but consistently low biomass when compared to the other lakes. All five lakes appeared more similar in zooplankton abundance when only density was considered, but total biomass

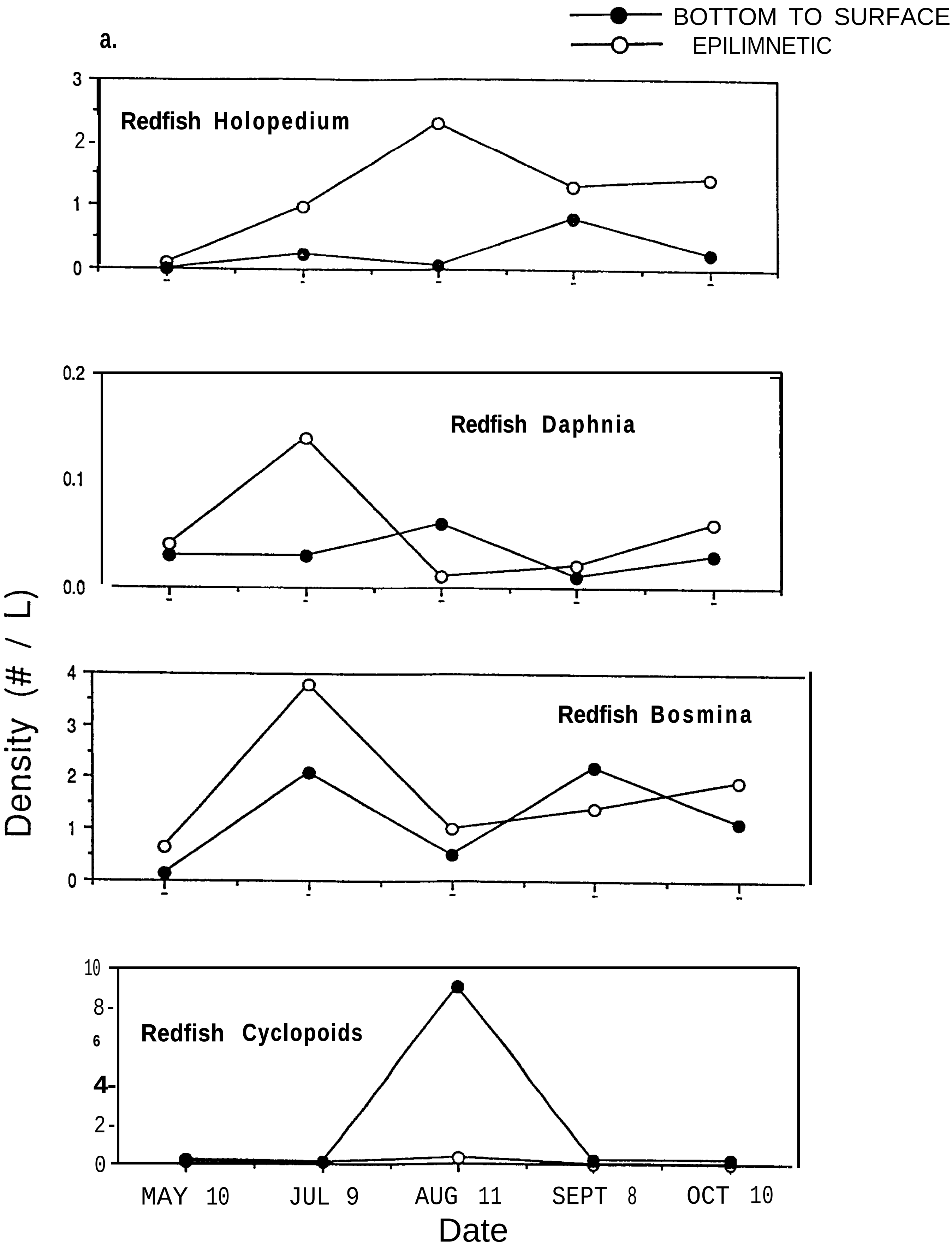
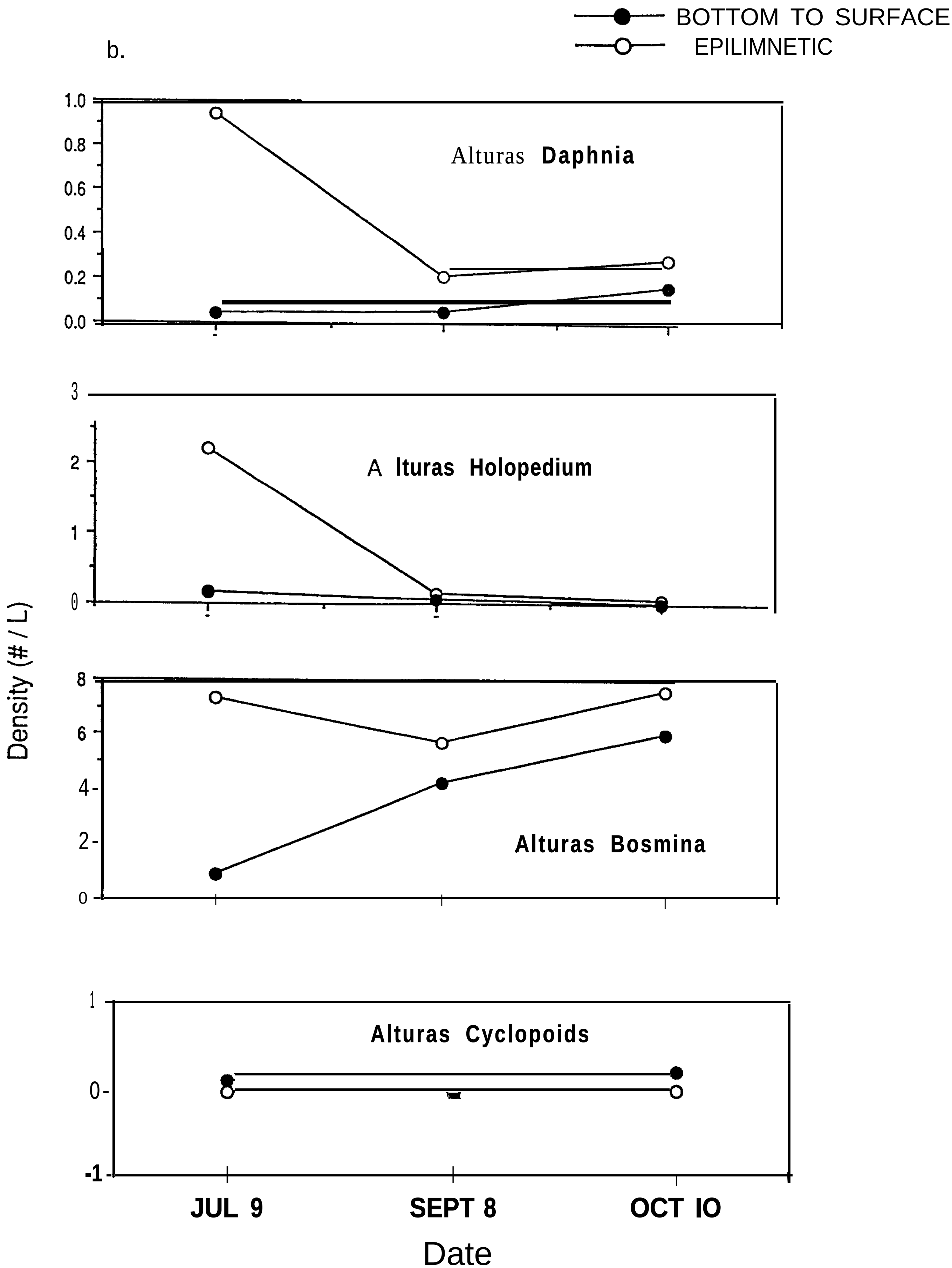
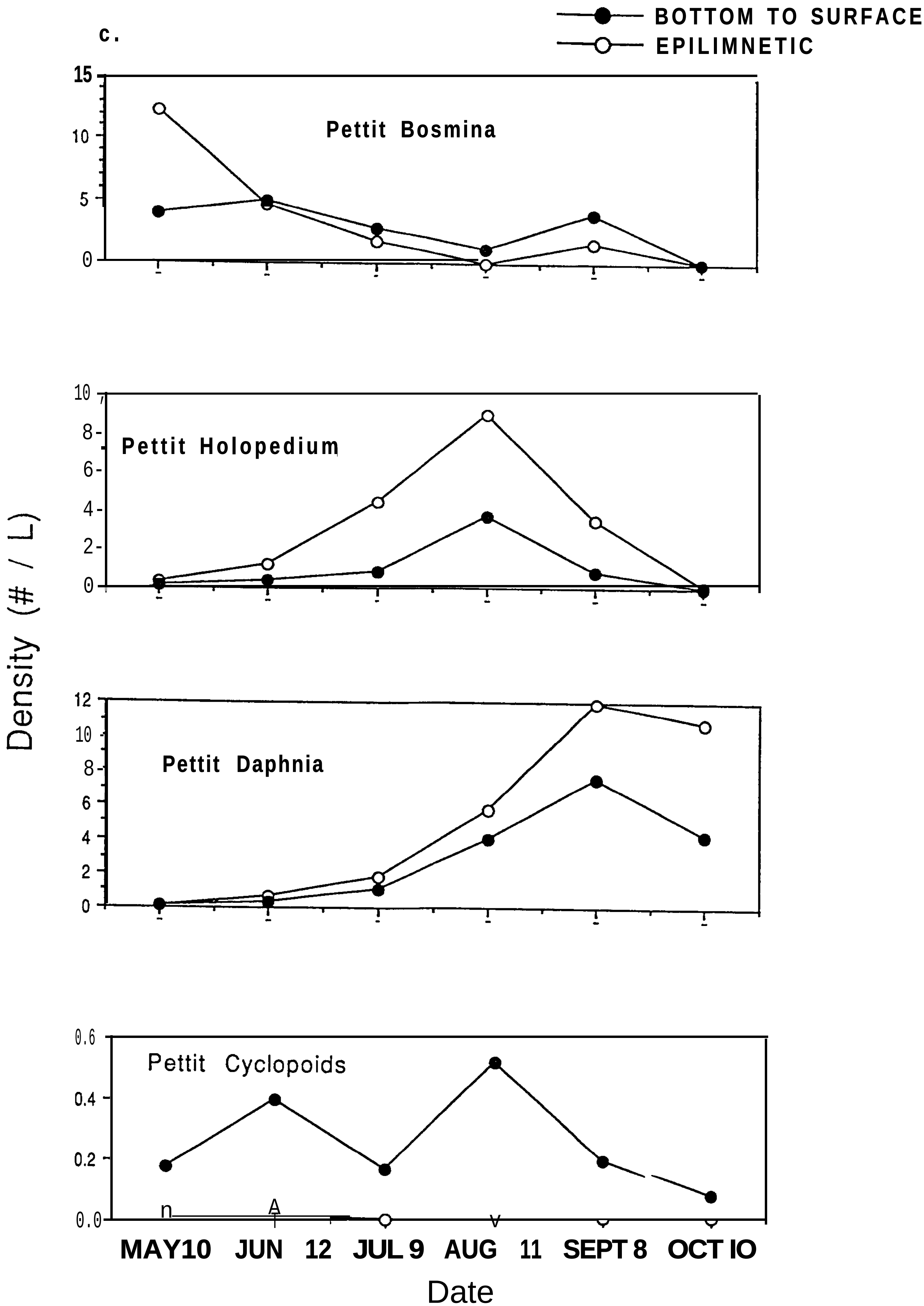


Figure 13. Zooplankton densities estimated from bottom to surface tows versus epilimnetic tows. a) Redfish b) Alturas c) Pettit d) Stanley e) Yellow Belly

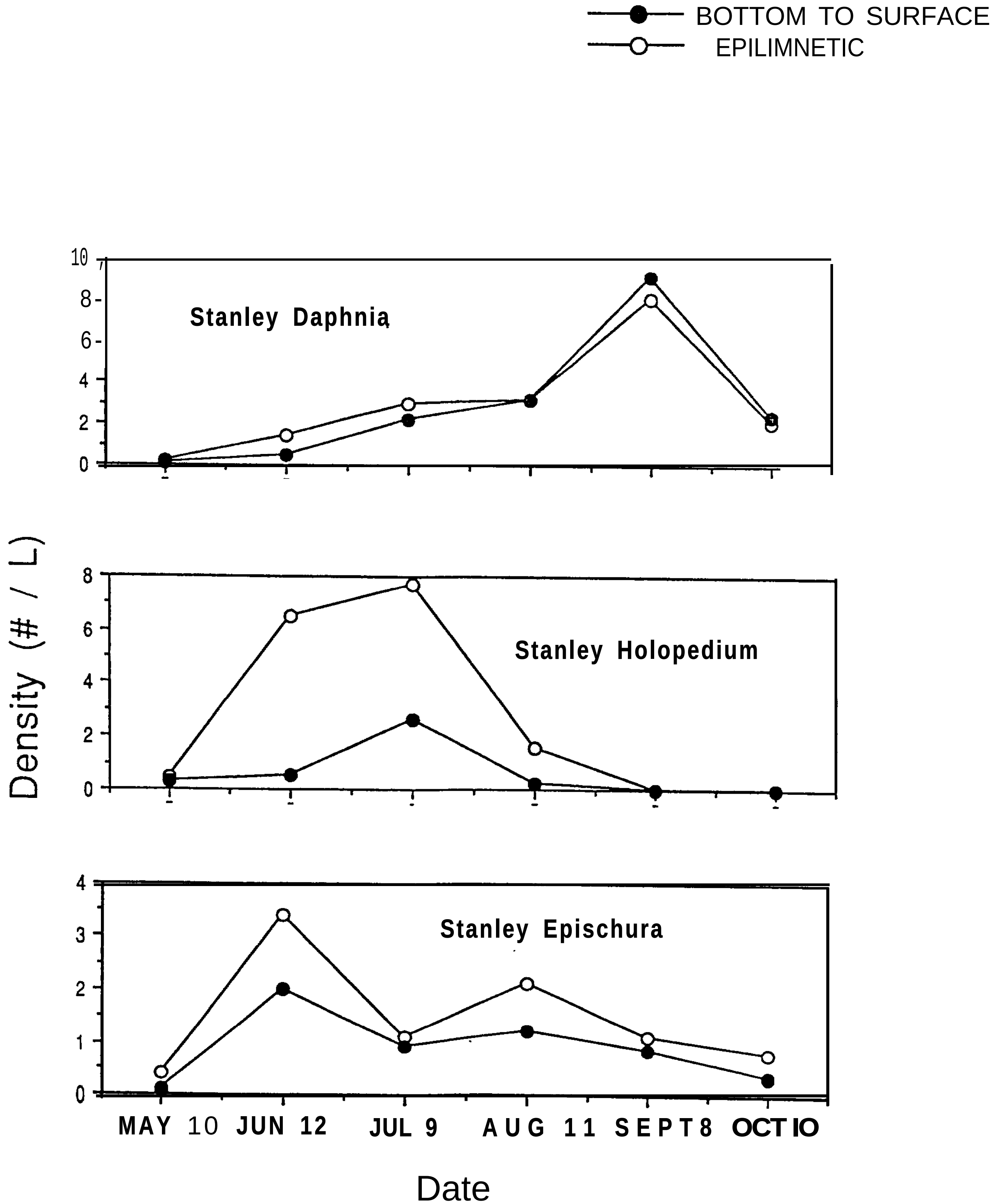


BOTTOM TO SURFACE
EPILIMNETIC
b.
Alturas Daphnia
A lturas Holopedium
Alturas Bosmina
Alturas Cyclopoids
Density (# / L)
JUL 9
SEPT 8
OCT IO
Date



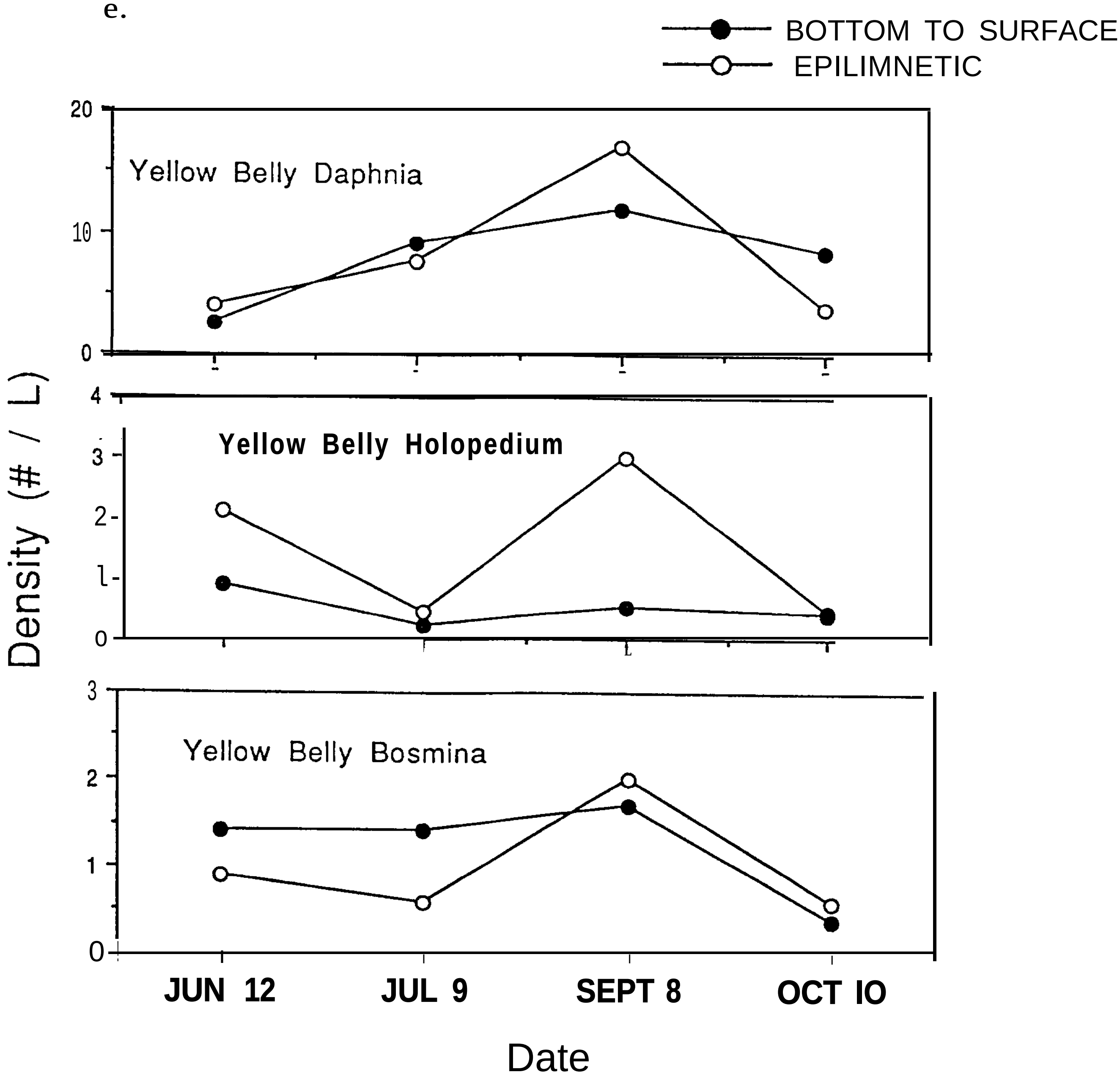
c.
BOTTOM TO SURFACE
EPILIMNETIC
Pettit Bosmina
15
10
5
0
Pettit Holopedium
10
8
6
4
2
0
Pettit Daphnia
12
10
8
6
4
2
0
Pettit Cyclopoids
0.6
0.4
0.2
0.0
Density (# / L)
MAY10 JUN 12 JUL 9 AUG 11 SEPT 8 OCT IO
Date

d.

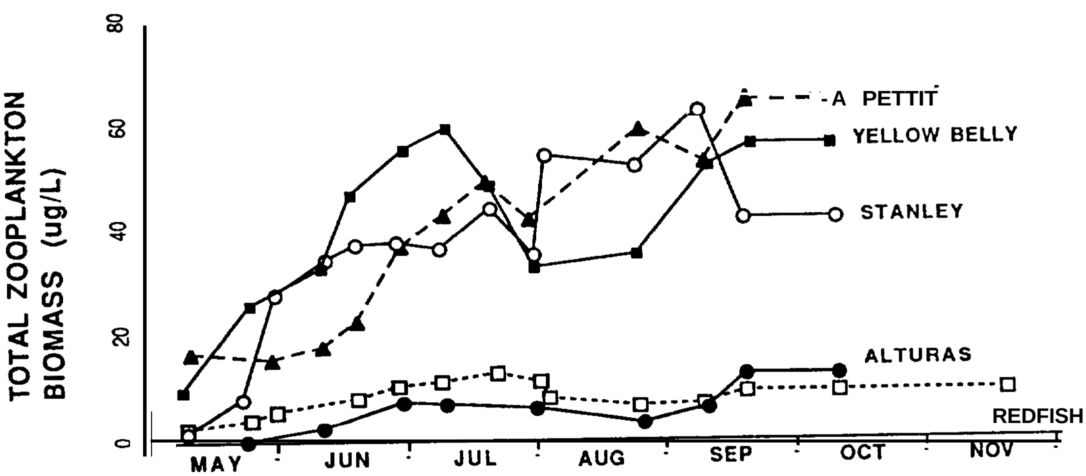


BOTTOM TO SURFACE
EPILIMNETIC
Stanley Daphnia
Stanley Holopedium
Stanley Epischura
Density (# / L)
0
2
4
6
8
10
0
2
4
6
8
0
1
2
3
4
MAY 10
JUN 12
JUL 9
AUG 11
SEPT8
OCT IO
Date

e.


BOTTOM TO SURFACE
EPILIMNETIC
Yellow Belly Daphnia
Yellow Belly Holopedium
Yellow Belly Bosmina
Density (# / L)
20
10
0
4
3
2
1
0
3
2
1
0
JUN 12
JUL 9
SEPT 8
OCT IO
Date

a.



b.

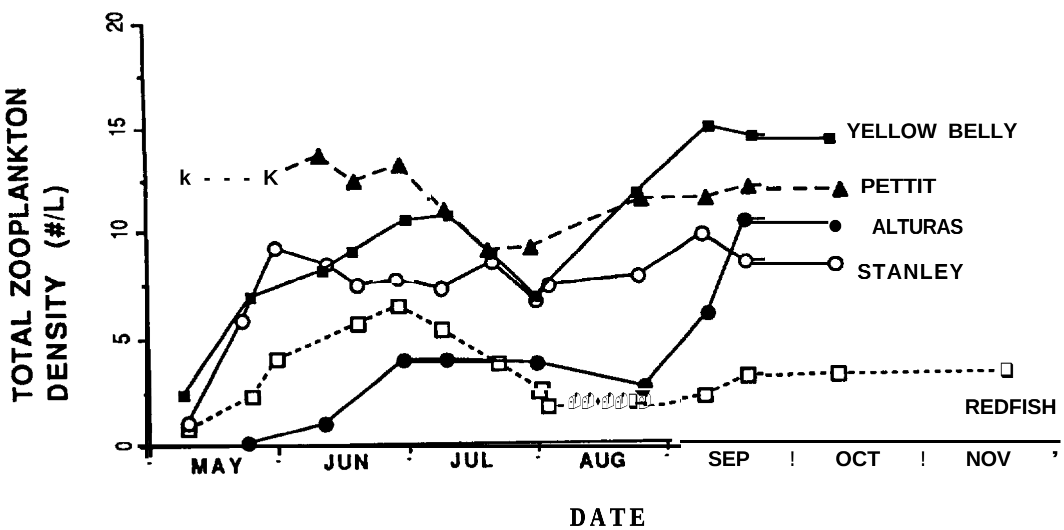


Figure 14. Seasonal distribution of total crustacean zooplankton: a) biomass b) density for all five lakes. Three-point running means are graphed to smooth the curves.

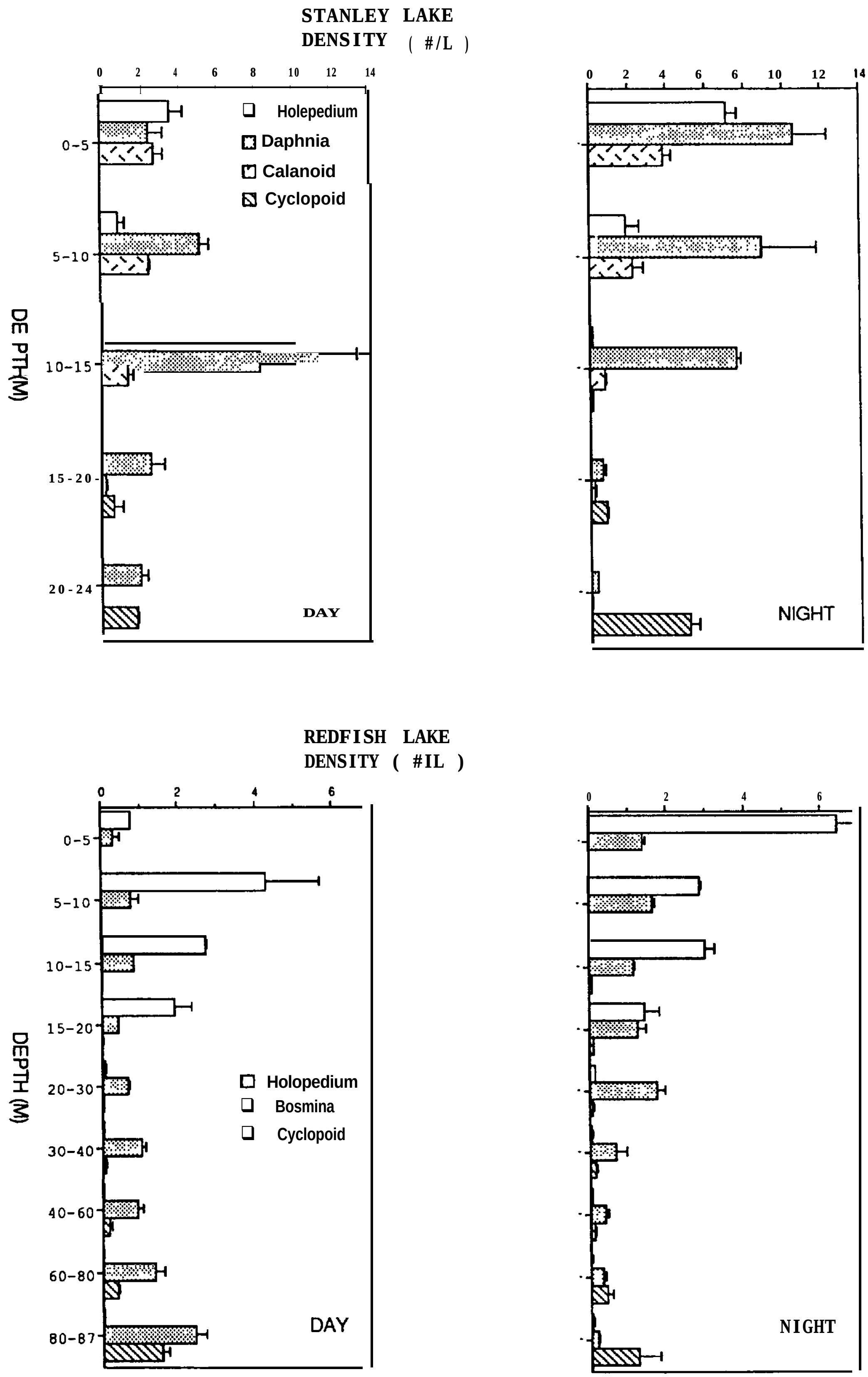


Figure 15. Diel vertical distribution of zooplankton densities from Stanley Lake (above) and Redfish Lake (below), August 3-4, 1992. Error bars denote the range of two samples.

estimates clearly indicated differences among the lakes (Figure 14).

Vertical distribution of zooplankton in Redfish Lake on August 3 indicated that different zooplankton taxa segregated according to depth during the day (Fig. 15). Holopedium was concentrated in the epilimnion and metalimnion attaining peak densities of 4 individuals L^{-1} in the 5-10 m strata. Cyclopoid copepods were most abundant in the hypolimnion attaining peak densities of 1.7 individuals L^{-1} in the bottom strata. *Bosmina* was present throughout the water column but was more concentrated in the deeper waters. *Daphnia* and *Polyphemus* were present in very low numbers throughout the water column.

At night the common cladocerans migrated up in the water column (Fig 15). *Holopedium* became most concentrated in the upper 5 m of the water column, and *Bosmina* moved from hypolimnetic regions to the epi- and metalimnion. Cyclopoid copepods exhibited small movements from the bottom waters to the metalimnion, but most individuals remained in the lower portions of the water column during both day and night periods.

An ANOVA examining the time by depth interaction suggested that each of the crustaceans moved up in the water column during the night. Holopedium moved from a mean depth of 10 m during the day to 7 m at night ($F_{1,8}$=17.8, P<O.001). *Bosmina* migrated from 46 m during the day to 15 m at night ($F_{1,8}$=28.8, P,O.OOl). Cyclopoid copepods migrated from a mean depth of 71 m during the day to 58 m at night, but the differences were not significant ($F_{1,8}$=0.38,

P>O.O5).

The vertical distribution of crustacean zooplankton in Stanley Lake was similar to that of Redfish. During the day Holopedium was concentrated in the epilimnion, whereas cyclopoid copepods were concentrated in the hypolimnion. *Daphnia* was present throughout the water column but most abundant in the l0-15 m strata. *Epischura* was most abundant in the upper portion of the water column. An ANOVA indicated that die1 differences in vertical distribution were significant for *Daphnia* which occupied a mean depth of 11.8 m during the day and 7.9 m during the night ($F_{1,4}$=4.70, P<O.O5). Holopedium also was located higher in the water column during the night ($F_{1,4}$=8.46, P<O.05). Cyclopoid copepods became more concentrated near the bottom of the lake during the night ($F_{1,4}$=21.5, P<O.01). No significant differences in the vertical distribution of *Epischura* was apparent in Stanley Lake.

DISCUSSION

Results from the limnological sampling indicate that all five lakes would be suitable for rearing juvenile sockeye salmon. Temperature and oxygen conditions indicate that a large portion of the volume of each lake would fall within the tolerance range of sockeye (< 17°C, >5 mg O_2/L, LeBrasseur et al. 1978). In Redfish Lake nearly all of the water column was within these tolerance ranges throughout the season. In the other lakes the bottom 5-15 m of water contained insufficient oxygen to support permanent occupation by sockeye salmon.

The ample volume of water with suitable temperature and oxygen conditions suggests that sockeye salmon could behaviorally select water depths that provide best conditions for growth and survival. Brett (1983) suggests that sockeye should choose water temperatures around 15°C to optimize conversion efficiency of food. This hypothesis would predict that juvenile sockeye salmon would reside in epilimnetic waters in the five lakes.

Light conditions indicated that sockeye salmon could feed visually during the day near the bottom of Stanley, Pettit and Yellow Belly Lakes (0.1% of surface light, Ali 1959, Levy 1990). Conversely, fish would cross the 0.1% surface light isolume at approximately 45 m in Alturas and 55 m in Redfish Lake. Although zooplankton densities are low in all the lakes, the high light environment should provide for sufficient foraging conditions for juvenile sockeye salmon.

Levy (1990) indicated that juvenile sockeye salmon in lakes with piscivorous fish populations were concentrated during the day at light levels that could be predicted from light extinction (k) according to the relationship:

$$\text{Depth} = 15.4\ k^{-1} + 1.23$$

These results caused Levy (1990) to hypothesis that juvenile sockeye salmon should behave so as to avoid visual predators during the day and choose an energetically efficient temperature at night. His hypothesis would predict that juvenile sockeye salmon would reside at the bottom all five lakes during the day, and move to the epilimnion of each lake at night. These results suggests that the high light environment in the Sawtooth Valley Lakes may make juvenile sockeye salmon particularly vulnerable to fish piscivores in that little daytime refuge for these prey fish would exist. Information on piscivore densities in the lakes will consequently be essential in assessing the potential survival of juvenile sockeye salmon.

A number of authors have derived sockeye growth or production values from nursery lakes given limnological information of the type collected in our study. Rieman and Myers (1992) indicted that Secchi transparency and epilimnetic chlorophyll levels provided the best predictors of juvenile kokanee growth in Idaho Lakes. Koenings and Burkett (1987) described a significant positive relationship between the volume of the euphotic zone and the density of sockeye smolts in a series of Alaskan lakes. In addition to these regression approaches, Walters et al. (1991) and Budy et al. (in preparation) have constructed simulation models to examine the relationship between zooplankton biomass and juvenile sockeye growth within a bioenergetics context (Beauchamp et al. 1989).

Each of these approaches can be used to assess the potential for each of the five lakes to serve as a rearing environment for the endangered stock of sockeye salmon. Each of these models provides a different ranking of the lakes in terms of sockeye potential (Table 3). The chlorophyll and Secchi relationships (Rieman and Myers 1992) indicated that Stanley would provide the best conditions for juvenile growth and that Pettit would provide the worst. Sockeye growth potential varied among the other lakes

Table 3. Potential growth and production of juvenile sockeye salmon in five lakes of the Sawtooth Valley. Chl (chlorophyll) and Secchi relationships from Rieman and Meyers (1992), EZ (euphotic zone) model from Koenings and Burkett (1987), ZOOP (zooplankton/energetics) model for Budy et al. (in prep). Values represent output from the model in either lengths of age-0 fish in September (mm TL) or production of smolts (# / ha). The number in parentheses refers to the rank given each lake in terms of sockeye production for a particular model. The last row of data refers to O.nerka collected in mid-water trawls. NA indicates that no data were collected.

	LAKE				
MODEL	Redfish	Alturas	Pettit	Stanley	Yellow Belly
Chl (mm TL)	99	100	98	108	99
(Rank)	(3.5)	(2)	(5)	(1)	(3.5)
Secchi (mm TL)	65	67	43	134	79
(Rank)	(4)	(3)	(5)	(1)	(2)
EZ (smolts/ha)	791	547	780	425	386
(Rank)	(1)	(3)	(2)	(4)	(5)
ZOOP (mm TL)	76	76	84	84	84
(Rank)	(4.5)	(4.5)	(2)	(2)	(2)
Lake (mm TL)	65	55	NA	95	NA
(Rank)	(2)	(3)	NA	(1)	NA

with regard to Secchi and chlorophyll relationships. The euphotic zone model (Koenings and Burkett 1987) predicted that Redfish and Pettit would produce almost 800 smolts per hectare (Table 3), whereas Stanley and Yellow Belly would produce only half that amount. Preliminary simulations of a zooplankton foraging-energetics model (Budy et al. in prep.) suggest that growth of juvenile sockeye salmon would be greatest in Stanley, Yellow Belly and Pettit Lakes and poorest in Redfish and Alturas (Table 3).

A comparison of the weight of 0. nerka captured in midwater trawls in September of 1992 with the rankings of each of the potential sockeye growth/production models suggests that the Secchi and zooplankton model provide the closest fit to the observed growth of juvenile 0. nerka in the lake (Table 3). The chlorophyll model predicts larger fish than occurred in trawl catches from the lakes. Predictions from the Secchi model were similar to the observed size of fish captured in Redfish Lake, but predicted larger fish than were captured in Stanley Lake. The zooplankton simulation model correctly ranked the growth of fish in the lakes, but the range of fish lengths among the lakes was greater than predictions from the simulations. It was unlikely that the euphotic zone production model would provide a good ranking of potential production of sockeye salmon in that this model was designed for use with stained or glacial lakes where light limitation of phytoplankton is common.

Results of this study indicate that each of the five lakes could support juvenile sockeye salmon, but that the potential growth and survival of these fishes would vary several-fold among the lakes. The higher zooplankton biomass exhibited in Stanley, Pettit and Yellow Belly Lakes indicates that growth of juvenile sockeye salmon would be greater in these lakes compared to Redfish and Alturas. Surprisingly, Redfish is the only lake that now supports a sockeye run, and Alturas is the only other lake to have had recent adult sockeye returns (Bowles and Cochnaur 1984). It is likely that the higher density of kokanee in these two lakes has suppressed the number and size of crustacean zooplankton in recent years.

Although Stanley, Pettit and Yellow Belly Lakes likely have better conditions for growth of juvenile sockeye salmon than does Redfish, the impact of piscivorous fish in these systems could be higher (Beauchamp et al., Chapter 3). Enhanced piscivore assessment and additional modeling efforts are needed before the tradeoff between sockeye growth and survivorship can be properly evaluated for these lakes. Research designed to address this tradeoff should be given high priority. Consideration of both potential growth and survival of juvenile sockeye salmon is essential before plans to rehabilitate this endangered stock are finalized.

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CHAPTER 2

NUTRIENT LIMITATION OF PHYTOPLANKTON IN OLIGOTROPHIC LAKES OF THE SAWTOOTH VALLEY, IDAHO

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Introduction

Phytoplankton production in lake ecosystems is frequently controlled by the amount and types of nutrients available. Studies examining primary productivity and lake trophic status have identified phosphorus (P) and/or nitrogen (N) as limiting nutrients (Smith 1982, Elser et al. 1990), as well as minor- and micro-nutrients (Goldman 1965, Wurtsbaugh and Horne 1983, Lovstad and Bjorndalen 1990). Others have demonstrated that phytoplankton production is also controlled by zooplankton grazing exerting "top-down" effects (Kyle et al. 1988) and by an interaction of top-down effects and nutrient limitations (Vanni and Temte 1990, Hansson 1992).

Nutrient limitation has frequently been studied to determine which nutrient(s) should be reduced to control lake eutrophication (Schindler 1974). More recently, investigators have added nutrients to lakes to stimulate plankton production and, subsequently, fish growth and survival (Hyatt and Stockner 1985, Kyle et al. In press). This later strategy has been used to establish or augment salmon runs for commercial exploitation (Kyle et al. 1988).

Nutrient additions have also been used to reverse declines in lake productivity due to decreases in anadromous salmon populations (Koenings and Burkett 1987). Adult salmon spawn and die soon after their return from the ocean. The decomposition of their carcasses often provides significant amounts of marine-derived nutrients into the freshwater ecosystems (Juday et al. 1932; Kline et al. 1990).

Koenings and Burkett (1987), for example, calculated that sockeye salmon carcasses contributed nearly 60% of the annual phosphorus loading to an Alaskan lake. Since phosphorus loading is often important in determining chlorophyll a levels in lakes (Vollenweider 1976; Dillon and Rigler 1974) declines in returning salmon can lead to decreases in lake productivity.

In the Sawtooth Valley of Idaho, USA, the declining anadromous runs of the endangered Snake River sockeye salmon (Oncorhvnchus nerka) has resulted in decreasing nutrient loading to five salmon rearing lakes. 0. nerka returning to the lakes have declined more than 99% over the last 40 years, primarily because dams on the Snake and Columbia rivers allow severe predation on migrating smolts (Rieman et al. 1991). Bjornn et al. (1968) reported that the number of adult sockeye returning to one of the lakes, Redfish Lake, numbered 4,400 in 1955, but that was "probably only a small fraction of the number which returned during the 1800's." In contrast, a total of only seven adults returned to the lake during the past four years (1989-1992). Because of the precarious state of the population, the Snake River sockeye salmon was listed under the Endangered Species Act in 1991. The decline of the Snake River sockeye has undoubtedly reduced nutrient loading and may have contributed to the current low fish production in the lakes.

Although the primary threat to the Snake River salmon is mortality during downstream migration, it may be possible to help save the species by fertilizing the rearing lakes to return them a higher level of productivity. This should increase the growth rates and abundances of wild and hatchery-produced sockeye salmon that will be introduced into the lakes. Here we report on laboratory and field experiments designed to: (1) test if nutrient additions can be used to stimulate algal production in these oligotrophic lakes; (2) determine what nutrient(s) are limiting production, and; (3) determine if current zooplankton populations are important in regulating phytoplankton growth and abundance.

Study Area

Characteristics of the five study lakes, Alturas, Pettit, Redfish, Stanley, and Yellow Belly Lakes are shown in Table 1. The lakes are located in the Sawtooth National Recreation Area at elevations between 1985 and 2157 m. The lakes' catchments lie mostly within the pristine Sawtooth Wilderness Area, draining the east side of the granitic Sawtooth and Smoky Mountains. The lake basins were carved by glaciers which advanced just beyond the mouths of the mountain valleys, depositing large moraines (Alt and Hyndman 1989). The lower portions of the drainages support mixed aspen and fir forests (Franklin and Dyrness, 1973).

The study lakes are popular regional destinations for recreational purposes (e.g. boating, fishing, camping, hiking, picnicking). The development on the lakes consists of a cabin/lodge complex on Redfish Lake, 23 vacation cabins on Pettit Lake, and developed campgrounds at Alturas, Redfish, and Stanley Lakes. All lakes except Yellow Belly Lake are accessible by hard-surface roads and have boat ramps.

Table 1. Sawtooth Valley Lakes physical and morphometric data

Lake	Latitude	Longitude	Elev. (m)	Drainage Area(km2)
Redfish	44" 07' N	114" 56' W	1996	108.1
Alturas	43" 55' N	114" 52' W	2138	75.7
Pettit	43" 59' N	114" 53' w	2132	27.4
Stanley	44" 15' N	115" 03' w	1985	39.4
Y. Belly	44" 00' N	114" 53' w	2157	30.4

Lake	Area km^2	Mean Depth (m)	Max Depth (m)	Volume (10^6 m^3)	1992 Outflow (10^6 m^3)	Water Residence Time (yr)
Redfish	6.15	44	91	269.9	50.3	5.4
Alturas	3.38	32	53	108.2	23.6	4.6
Pettit	1.62	28	52	45.0	7.41	6.1
Stanley	0.81	13	26	10.4	11.2	0.9
Y. Belly	0.73	14	26	10.3	14.6	0.7

Nutrient sampling from April through November of 1992 showed the lakes to be oligotrophic. Mean epilimnetic NO_3-N values ranged from 4.3 to 10.1 μg/L, while PO_4-P ranged from 1.3 to 2.4 μg/L (Table 2 and Appendix 4). Lake water residence times and outflow data in Table 1 were computed from field measurements collected in 1992 (see Appendix 2). Additional limnological characteristics of the lakes are available in Budy et al. (Chapter 1).

Table 2. Seasonal mean epilimnetic nutrient levels for the Sawtooth Valley Lakes, April-November, 1992

Nutrient	Alturas	Pettit	Redfish	Stanley	Y. Belly
NO_3-N (μg/L)	4.3	4.6	7.0	4.4	10.1
PO_4-P (μg/L)	1.3	2.1	2.0	1.7	2.4

Methods

Two types of assays, *in situ* and *in vitro,* were conducted in 1992. *In situ* assays were conducted in June, July, and September in order to understand nutrient limitation during the important summer growing season in the five lakes. Additionally, we conducted the *in* vitro bioassays in May, July, and September on water from Redfish Lake in order to study some parameters of nutrient limitation in more detail under controlled laboratory conditions.

In Situ Experiments

In situ bioassays were conducted in the study lakes using translucent, collapsible 10 L polyethylene containers (cubetainers). Our tests showed that the containers transmitted nearly 100% of incident light. They were normally filled with epilimnetic lake water from a depth of 2-5 m collected with a diaphragm pump. The cubetainers were shaded during filling and subsequent sampling to avoid photo-inhibition of the phytoplankton. Two to three replicates of each treatment were used.

At the start of an experiment we made nutrient additions randomly to the cubetainers using an automatic micro-pipette. The treatments tested were (1) control (C), (2) nitrogen and phosphorus additions (NP), (3) nitrogen, phosphorus, and minor and micro-nutrient additions (NPM), or (4) nitrogen, phosphorus, and zooplankton additions (NPZ). Nutrient added to the cubetainers are given in Tables 3a and 3b.

Table 3a. Macro-nutrient concentrations used in bioassays of Sawtooth Valley lake waters, 1992 (note: differences in concentrations due to measurement errors).

Month	Bioassay Type	NO,-N (1)	NH,-N (1)	PO,-P (2)
June	*In situ*	0.187 M	0.187 M	0.0247 M
July	*In situ*	0.161 M	0.161 M	0.0201 M
Sept.	*In situ*	0.161 M	0.161 M	0.0203 M
July	*In vitro*	0.170 M	0.170 M	0.0203 M
Sept.	*In vitro*	0.170 M	0.170 M	0.0204 M

(1) Added as NH_4NO_3. (2) Added as KH_2PO_4.

Table 3b. Minor and micro-nutrient concentrations used in bioassays of Sawtooth Valley lake waters. These nutrient treatments were used in the *in situ* and in *vitro* bioassay of May, June and July, 1992. (*=nutrient only used in May & June.)

Nutrient	Concentration (µm)	Form
Boron	0.004	H_3BO_3
Cadmium	0.002	
Cobalt	0.003	
Cooper	0.0005	$CuSO_4$
Iron & HEDTA	0.007	$FeCl_3$+HEDTA
*Magnesium	1.0	$MgSO_4 \cdot 7\ H_20$
Manganese	0.007	$MnCl_4 \cdot H_20$
Molybdenum	0.00015	$Na_2Mo_04 \cdot H_20$
Nickel	0.002	
Potassium	14.0	
Silicon	0.3	K_2SiO_3
Sulphur	3.0	
Zinc	0.005	$ZnSO_4 \cdot 7\ H_20$

Zooplankton additions were tested to determine if zooplankton grazing could keep algal standing crops from increasing at enriched nutrient levels. To increase zooplankton in the NPZ treatments, we filtered water through 153-165 µm netting to collect crustacean plankton. In June the plankton was collected by pumping 2-3 m water through the netting. Subsequent analyses of the zooplankton in the cubetainers at the end of the experiment indicated, however, that densities were similar in the controls and zooplankton treatments, perhaps because the animals were avoiding the upper epilimnetic waters. To try to alleviate this problem in July, zooplankton were collected using a bottom to surface haul with a 153 μm zooplankton net. Aliquots of these zooplankton were added to cubetainers to increase densities ca. 300% above the controls. The cubetainers were mixed and placed in plastic crates and incubated at 5 $\pm$ 0.5 m.

After 5 and 10 days we collected 250 ml water samples from each cubetainer for analysis. Two replicate 50 ml aliquots from each sample were filtered through 0.45 pm cellulose acetate filters which were subsequently extracted for 24-48 hours in 6 ml of 100% methanol. Chlorophyll *a* and phaeophytin where then measured using a Turner 111 Fluorimeter (Holm-Hansen and Riemann 1978). For some samples we preserved phytoplankton in Lugol's solution for subsequent identification, counting and biovolume estimates using methods described in Budy et al. (Chapter 1).

In June and July, we tested NP, NPM, and NPZ treatments of epilimnetic water in four (June) or five lakes (July). In September, we tested the effects of NP additions to both epilimnetic water (5 m) and to metalimnetic water collected and incubated in the metalimnetic deep chlorophyll maxima of all five lakes (Figure 1). Light intensities and temperatures at incubation depths (Table 4) were made at least once during each experiment with a LiCor 188B radiometer equipped with a 4II PAR sensor, and a YSI thermistor.

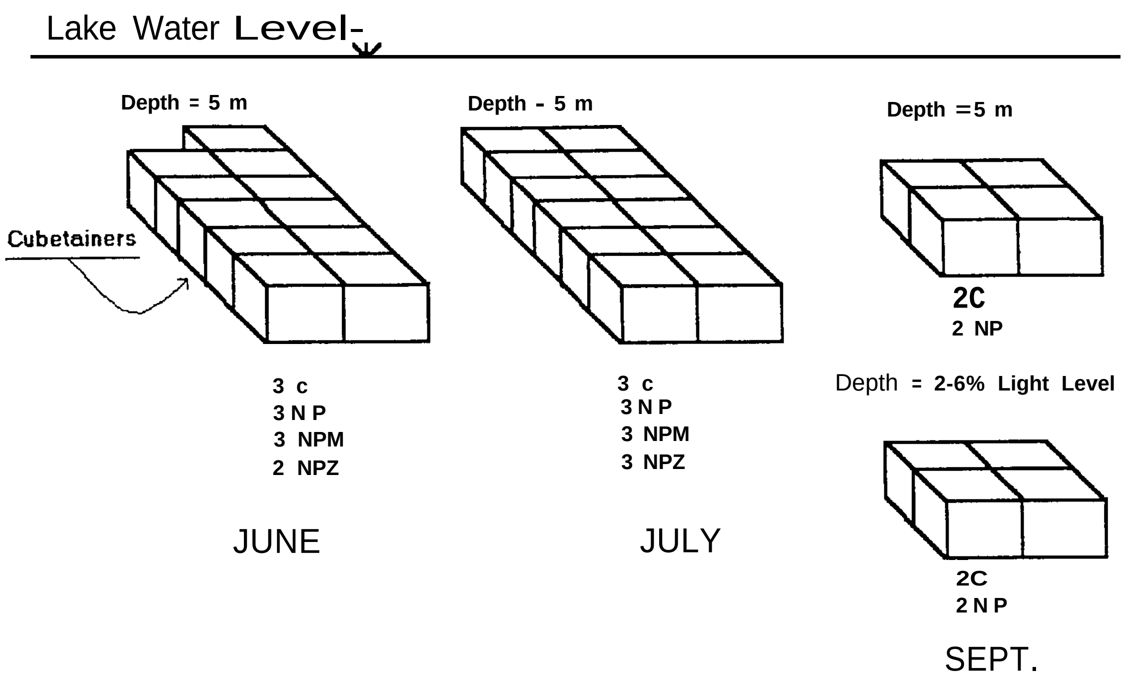

Fig. 1. Experimental design by month for *in situ* bioassays for Sawtooth Valley Lakes, Id., in 1992. c = control; NP = nitrogen + phosphorus treatment; NPM = nitrogen + phosphorus + minor and micro nutrients treatment; NPZ = nitrogen + phosphorus + zooplankton treatment. Only two NPZ treatments were tested in June due to a shortage of containers.

cubies.bmp

Table 4. Environmental conditions during the in *situ* bioassays in 1992. The experimental cubetainers were incubated either in the epilimnions (5 m, all months) or metalimnions (Sept.) of the lakes. (Z = depth, %SL = % surface light,- NA.= not available).

	June Bioassays (10-21 June)			July Bioassays (20 July-1 Aug.)			Sept. Bioassays (20-8 Sept.)		
Lake	Z	%SL	°C	Z	%SL	°C	Z	%SL	°C
Alturas	5	39	12	5	57	16	5 26	48 2.3	14 5.3
Pettit	5	50	13	5	53	17	5 20	49 5.8	14 6.2
Redfish	5	45	14	5	52	16	5 28	52 2.6	13 5.4
Stanley	5	23	12	5	NA	15	5 13	23 2.4	13 9.3
Y. Belly	-	-	-	5	32	17	5 14	22 1.4	14 8.0

In *Vitro* Experiments

In May, July, and September we collected water from Redfish and Yellow Belly (May only) Lakes at the same time and places that water was collected for the *in situ* experiments. The water was held in 20-L cubetainers in ice chests, and transported the following day to Logan where the *in vitro* experiments were done. Unfiltered, 750 ml aliquots of lake water were placed in 1 liter polycarbonate flasks and incubated at light intensities of 150 $\mu E \cdot m^{-2} \cdot sec^{-1}$ (4 Pi, PAR sensor) with an 18:6 light:dark cycle at the current lake temperature. Nutrient treatments were the same as those in the *in situ* experiments, except that we individually tested additions of N and P. In the July experiment we also added

N+P at 1X, 2X, and 4X the normal concentrations (Table 3) to determine the degree of algal growth that could be stimulated. Each flask was swirled and randomly rearranged on the incubation table daily. Treatments were done in duplicate (May) or triplicate (July, September). After 5 or lo-days we took aliquots from each flask and analyzed them for chlorophyll as described above.

Results

In all cases the phytoplankton responded rapidly to additions of nitrogen and phosphorus. In Redfish Lake, for example, NP additions in July increased chlorophyll concentrations from 0.24 mg/m^3 at the start of the experiment to 1.07 mg/m^3 at 5 d and 3.92 mg/m3 after 10 d (Fig. 2). In this experiment, addition of the micro-nutrient mixture gave a slight, but insignificant, increase of chlorophyll levels above those of the NP mixture. Because the temporal increase was continuous in all of the experiments, the remaining results show only the response after 10 d.

Nutrient additions significantly ($p < 0.0001$) increased chlorophyll concentrations in all of the lakes (Fig. 3a). Initial and control treatments almost always had chlorophyll a concentrations << 1 mg/m^3, suggesting that the lakes were severely nutrient limited (Fig. 3a; Chapter 1). NP additions usually stimulated algal growth 200 to >1000% above control levels after 10 d (Fig. 3b). Addition of the minor and micro-nutrients increased chlorophyll levels above the NP treatments in 7 of 9 cases (Fig.

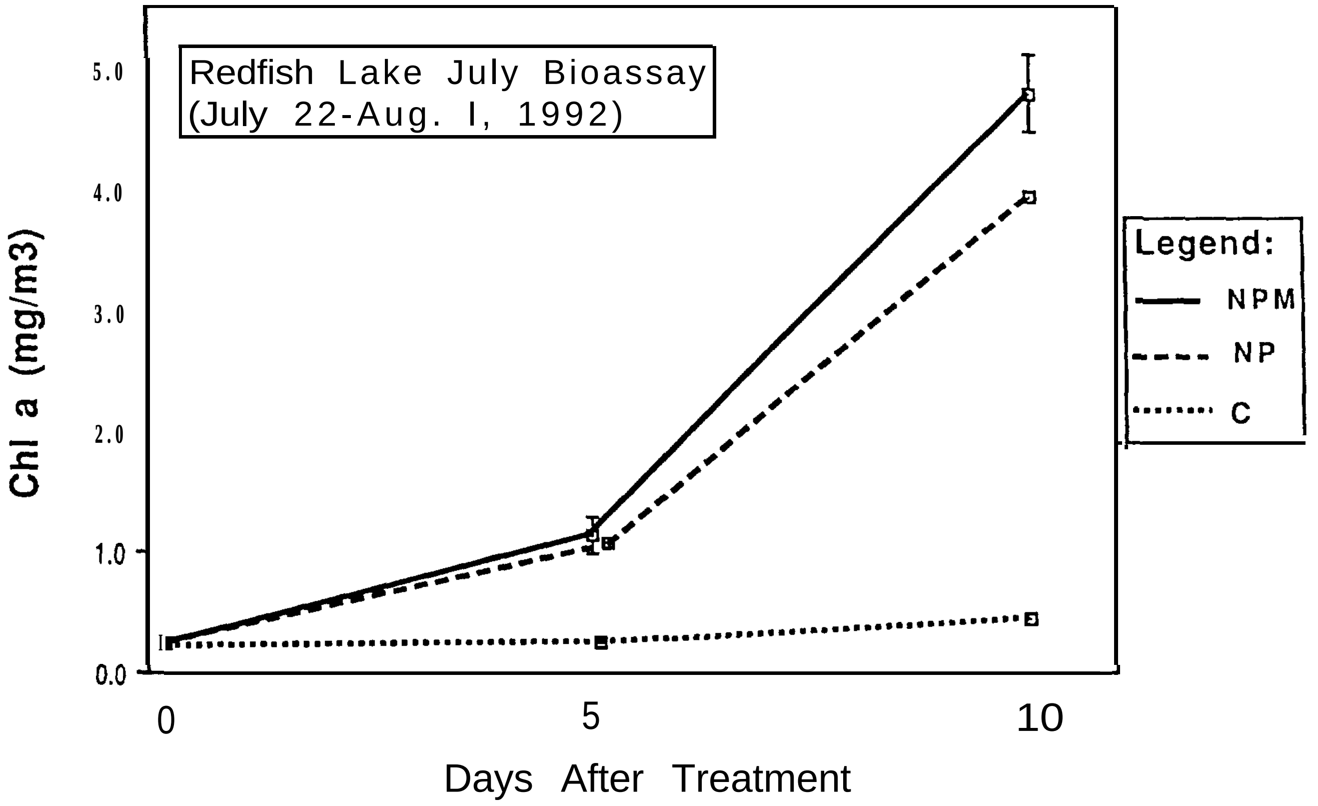

Fig. 2. Results of in situ epilimnetic (at 5 m) bioassays for Redfish Lake, Id., in July 1992. C = control treatment; NP = nitrogen + phosphorus treatment; NPM = nitrogen + phosphorus + minor and micro nutrients treatment. Error bars show 1 SE of the mean. N=3 for all treatments. Chlorophyll levels responded rapidly and temporally to nutrient additions. However, the addition of minor and micro nutrients did not have a significant effect.

mac: redfish temporal graph

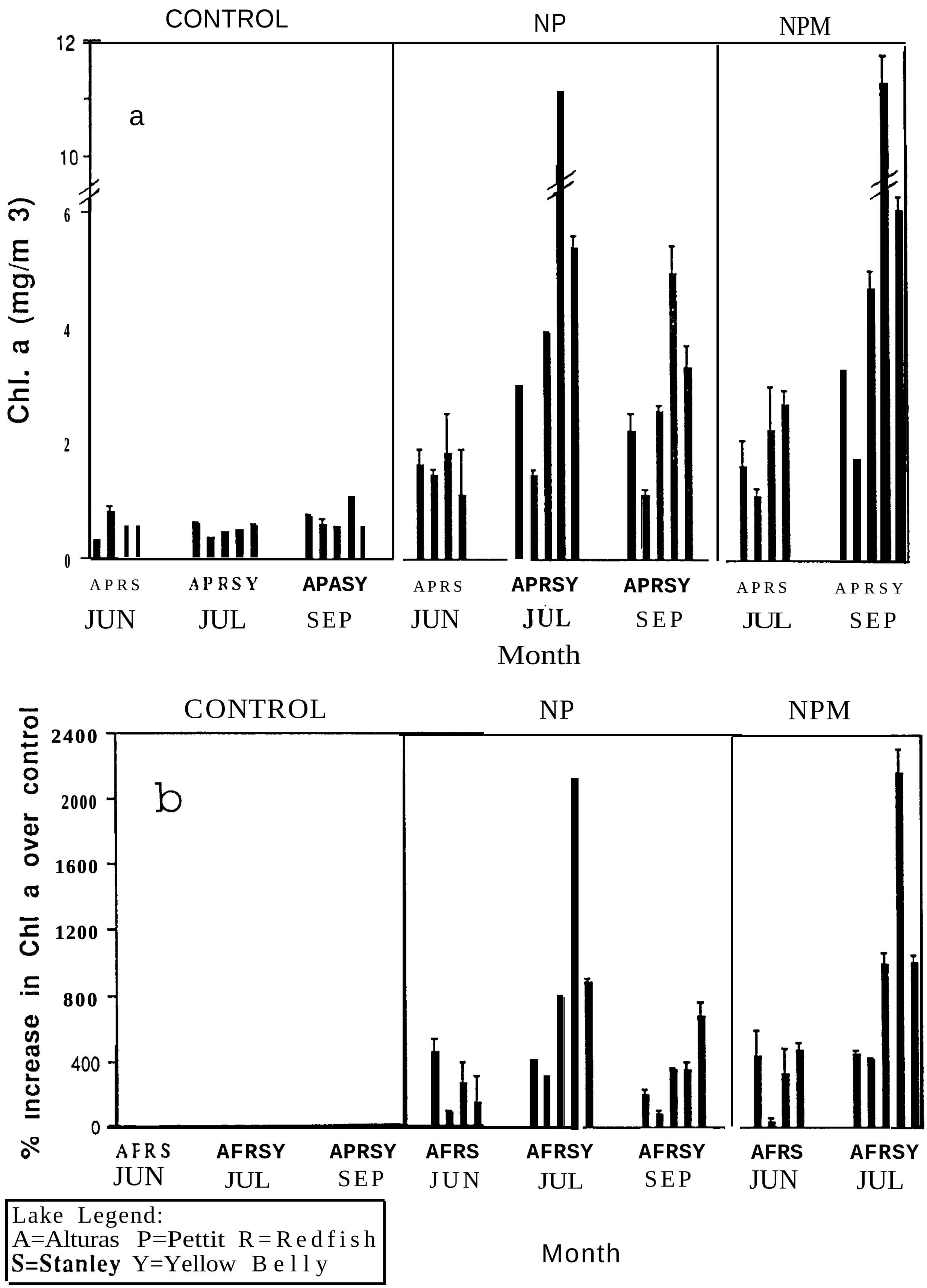

Fig. 3. Results of in *situ* epilimnetic (at 5 m) bioassays for Sawtooth Valley Lakes, Id., in 1992. NP=nitrogen + phosphorus treatment; NPM=nitrogen + phosphorus + minor and micro nutrients treatment. Error bars show 1 SE of the mean. N=3 for all treatments, except for the five NP treatments in September, when N=2. Graph (a) shows chl. a values and graph (b) show % increase in chl. a treatments over the controls.

Fig 3a - mac: bar increase Fig 3b - mac: per bar increase

3a,b), but in most instances these differences were small, and in only two cases did the responses approach significance (ANOVA, Redfish L. in July, $p = 0.06$; Yellow Belly L. in July, $p = 0.10$).

Considerable seasonal differences in the response to nutrient additions were apparent in most lakes (Fig. 4). In Pettit, Redfish, and Stanley Lakes, the responses to all epilimnetic treatments were significantly greater in July than in June or September (1 ANOVA per lake; all p values ≤ 0.025). In Yellow Belly Lake the response was also greater in July than in September ($p = 0.086$) but we did not test this lake in June. Algal response in Alturas Lake was also greater in July than in September, but this difference was not significant.

The NPZ treatments gave little indication that zooplankton additions increased grazing pressure on the stimulated phytoplankton production (Fig. 4). In fact, treatments with added zooplankton usually had <u>hiaher</u> chlorophyll levels than in treatments without added plankton (Fig. 4). In June, chlorophyll levels in NPZ treatments were higher than those in NP treatments in all four lakes but this stimulation only approached significance in Pettit Lake (ANOVA, $p = 0.08$). Analysis of zooplankton abundances at the end of the June experiment indicated that only Pettit Lake treatments had higher zooplankton densities, while NPZ treatments from the other lakes were similar to the NP treatments. In July, final chlorophyll levels were higher in the NPZ treatments than in the NP treatments in three of five lakes (Pettit, $p = 0.057$; Redfish, $p = 0.031$; Yellow Belly, $p = 0.08$). In Stanley

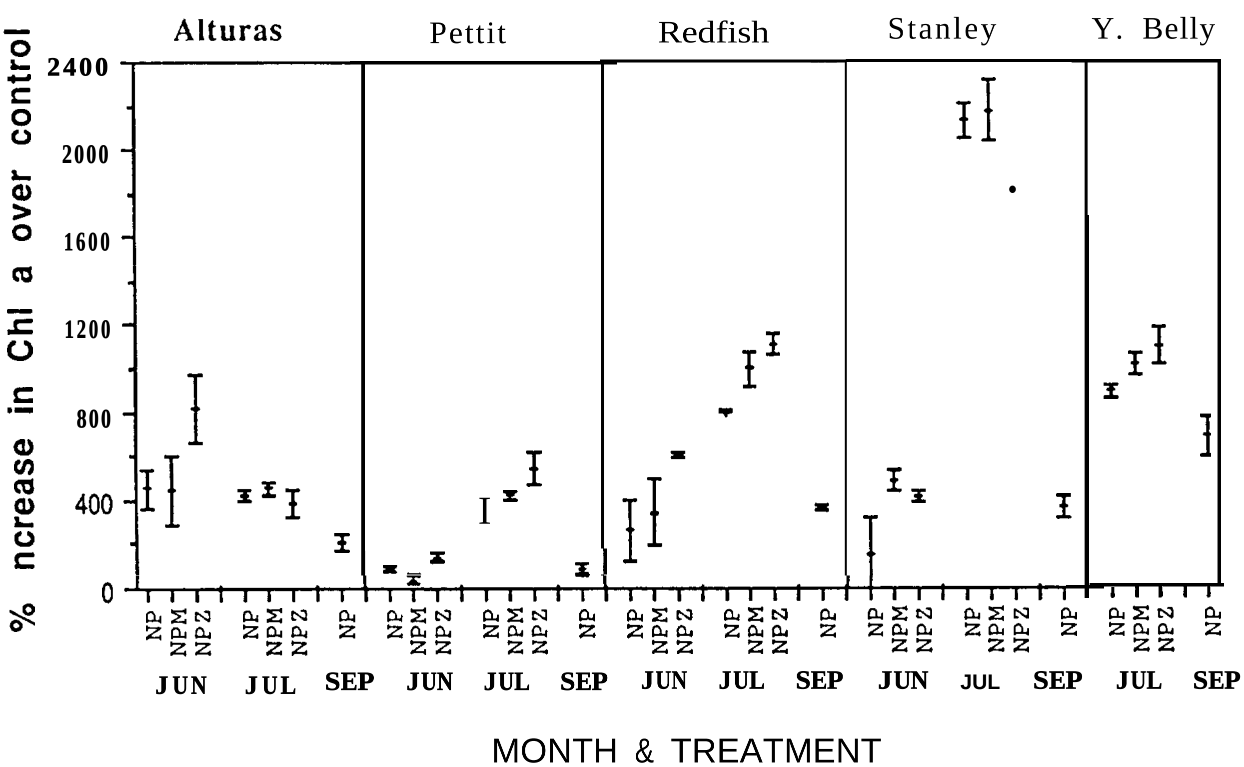

Fig. 4. Results of in *situ* epilimnetic (at 5 m) bioassays for Sawtooth Valley Lakes, Id., in 1992. NP = nitrogen + phosphorus treatment; NPM = nitrogen + phosphorus + minor and micro nutrients treatment; NPZ = nitrogen + phosphorus + zooplankton treatment. Error bars show 1 SE of the mean. N=3 for all treatments, except for the Sept. NP and the June NPZ treatments, when N=2. Graph shows % increase in chl. a treatments over the controls.

mac: np/npm/npz by lake

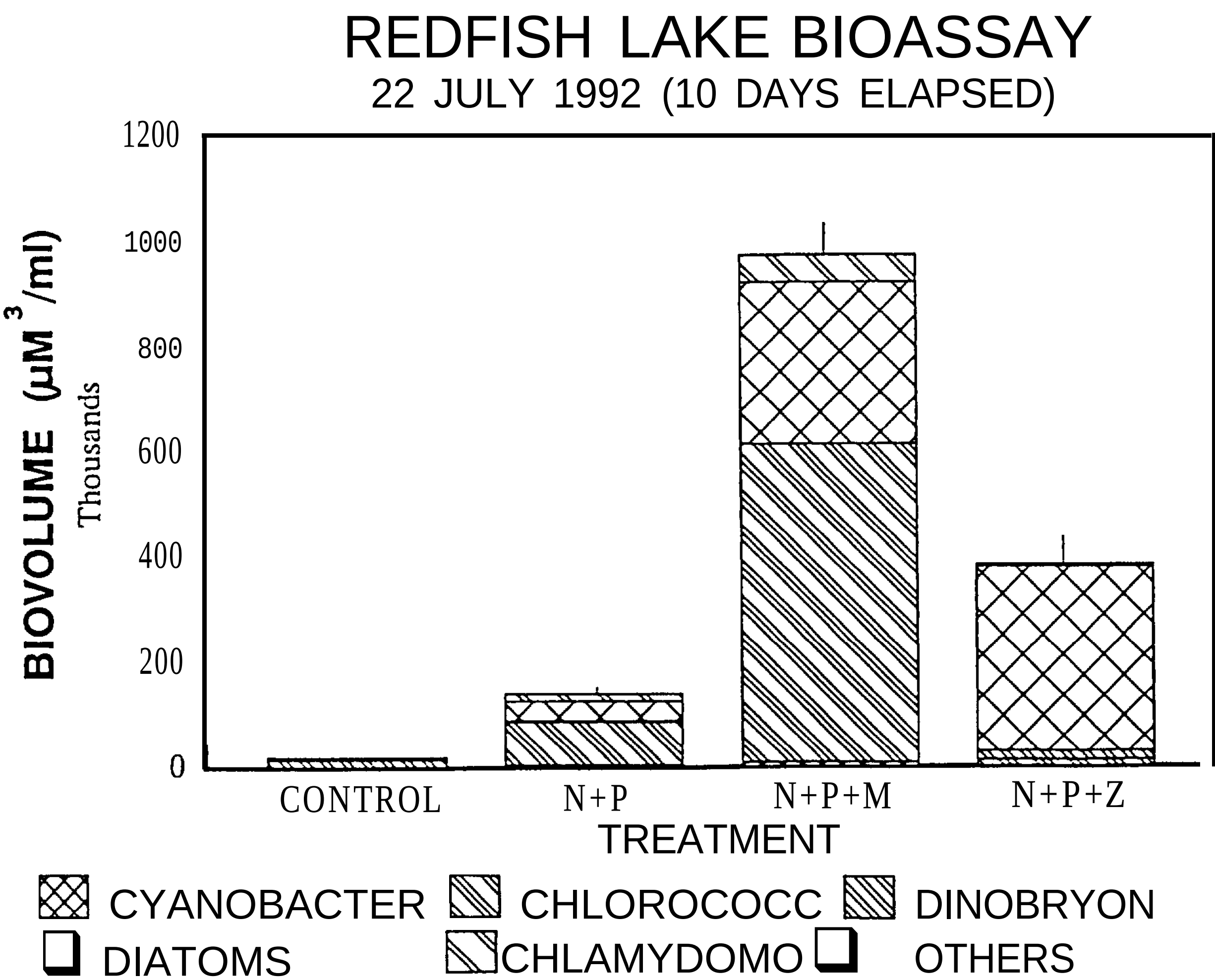

Figure 5. Effects of nutrient and zooplankton additions on the biovolume of phytoplankton in the 22 July - 1 August ***in*** situ bioassay experiment in Redfish Lake. Treatments: Control (n=3); N+P - nitrogen + phosphorus (n=3); N+P+M - nitrogen + phosphorus + minor and micro nutrients (n=2); N+P+Z - nitrogen + phosphorus + added zooplankton (3X normal lake densities) (n=2). Taxa key: Cyanobacter - small unicellular cyanobacteria; Chlorococc - Chlorococcales; Dinobryon - Dinobryon sp.; Diatoms - principally ***Fragillaria,*** Tabellaria, *Amphipleura;* Chlamydomo - ***Chlamydomonas*** sp. Error bars, when visible, show +l SE of the total biovolume.

Lake, however, chlorophyll levels were significantly _lower_ in the zooplankton treatments than in the NP treatments ($p = 0.016$), while in Alturas Lake the slight decrease in chlorophyll was not significant ($p = 0.59$). Although the zooplankton in the July bioassay has not yet been counted, cursory inspection indicates that much higher densities of zooplankton were added then than in the June experiment.

Enumeration and biomass estimates of the phytoplankton from the July _in situ_ experiment indicated that different taxa responded differently to the nutrient and zooplankton treatments (Fig. 5). The algal biovolume in the initial sample and the controls was dominated by _Dinobrvon_ sp. In the NP treatments this taxa nearly disappeared, but was replaced by small unicellular chlorococcales and diatoms that had 8-times greater biovolume than the control treatments. Treatments that received additional minor- and micro-nutrients (N+P+M) had about fifty times the biomass of controls after the lo-day incubation. These treatments were also dominated by chlorococcales, the diatoms _Frasillaria_ sp. (80%) and _Amphipleura_ sp. (20%), and a small component of _Chlamvdomonas_ sp.. Additions of zooplankton to N+P treatments inhibited or grazed down the small chlorococcales, leaving primarily the diatoms _Tabellaria_ sp. (93%) and _Fraqillaria_ (6%), and _Chlamvdomonas_. Note that the biovolume analysis of this experiment indicated a negative effect of zooplankton on the phytoplankton, while the chlorophyll analyses (Fig. 4) suggested the reverse for Redfish Lake in July.

Nitrogen and phosphorus additions stimulated phytoplankton growth in both the epilimnions and in the hypolimnions when tested during the September _in situ_ experiments (Fig. 6a). The metalimnetic water responded strongly to nutrient additions, reaching 8 and 13 mg/m^3 in Yellow Belly and Stanley Lakes, respectively. Nutrient additions to epilimnetic water, however, resulted in a greater _percent_ increase in chlorophyll levels than did additions to metalimnetic water in all lakes except Stanley (Fig. 6b). The greater % response in the epilimnion was significant in Alturas ($p = 0.057$), Redfish ($p = 0.008$), and Yellow Belly ($p = 0.038$) Lakes, but not Pettit Lake ($p = 0.31$). The greater % response in the metalimnetic water in Stanley was not significant ($p = 0.28$).

The results of the _in vitro_ laboratory experiments for Redfish Lake indicated that nitrogen more often limited algal growth more than did phosphorus, but that both nutrients were always co-limiting (Fig. 7). In May, neither N or P added alone stimulated chlorophyll levels, but N+P additions stimulated the phytoplankton about 400% above the controls after a 5-day incubation. In May we also tested water from Yellow Belly Lake and found that NP additions stimulated chlorophyll levels more than 800% above controls, while N and P added alone provided little stimulation (Appendix 6). In both July and September, nitrogen additions to Redfish Lake water increased chlorophyll levels slightly while phosphorus inhibited or had no effect on the algae when it was added alone. The two nutrients together, however, stimulated

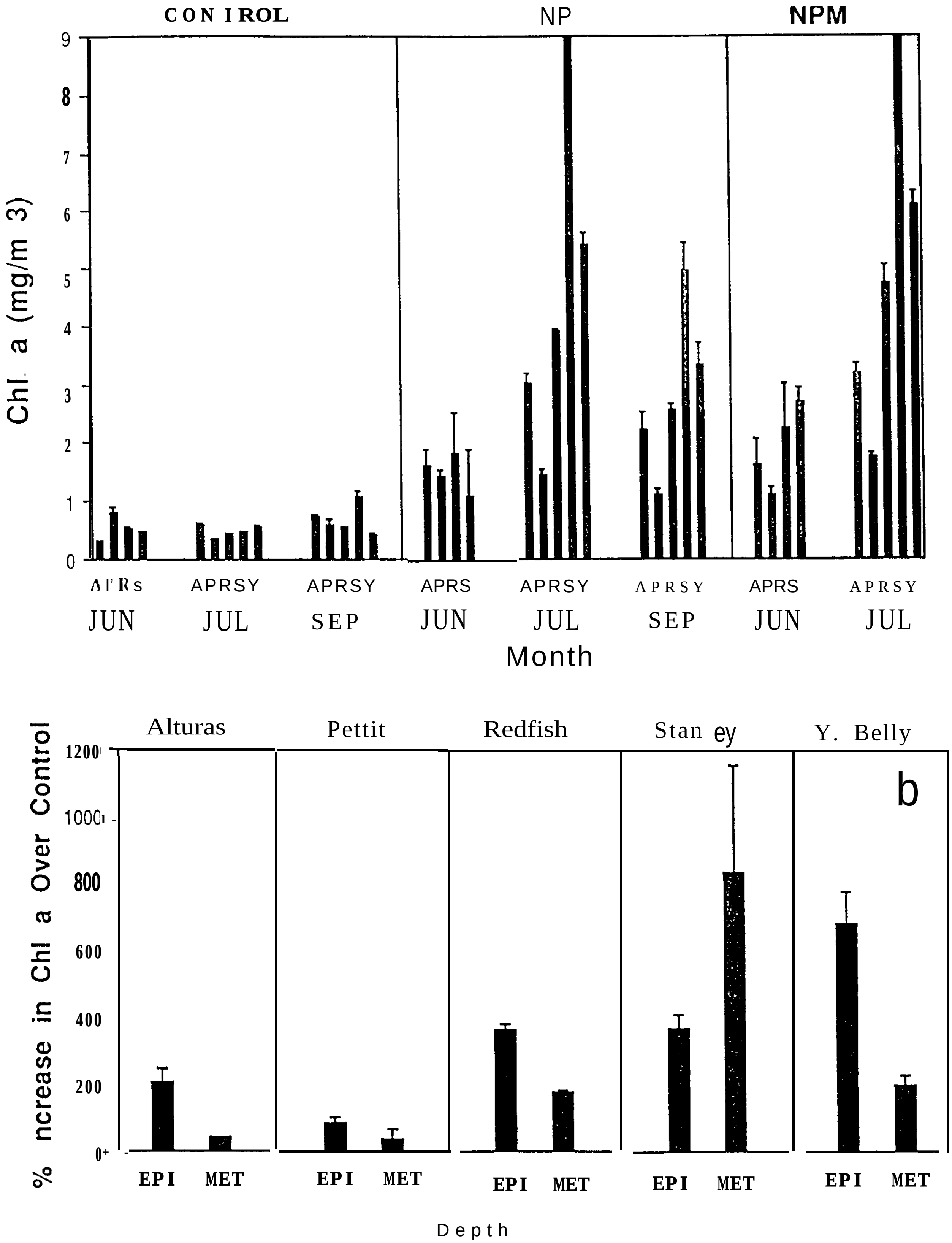

Fig. 6. Results of in situ epilimnetic (EPI) vs. metalimnetic (MET) bioassays for Sawtooth Valley Lakes, Id., in 1992. C=controls; NP=nitrogen + phosphorus treatments. Error bars show 1 SE of the mean. N=2 for all treatments. Graph (a) shows chl. ***a*** values and graph (b) shows % increase in chl. ***a*** treatments over the controls.

Fig 6a - mac: deep v. shallow **Fig 6b - mac: per deep v. shallow**

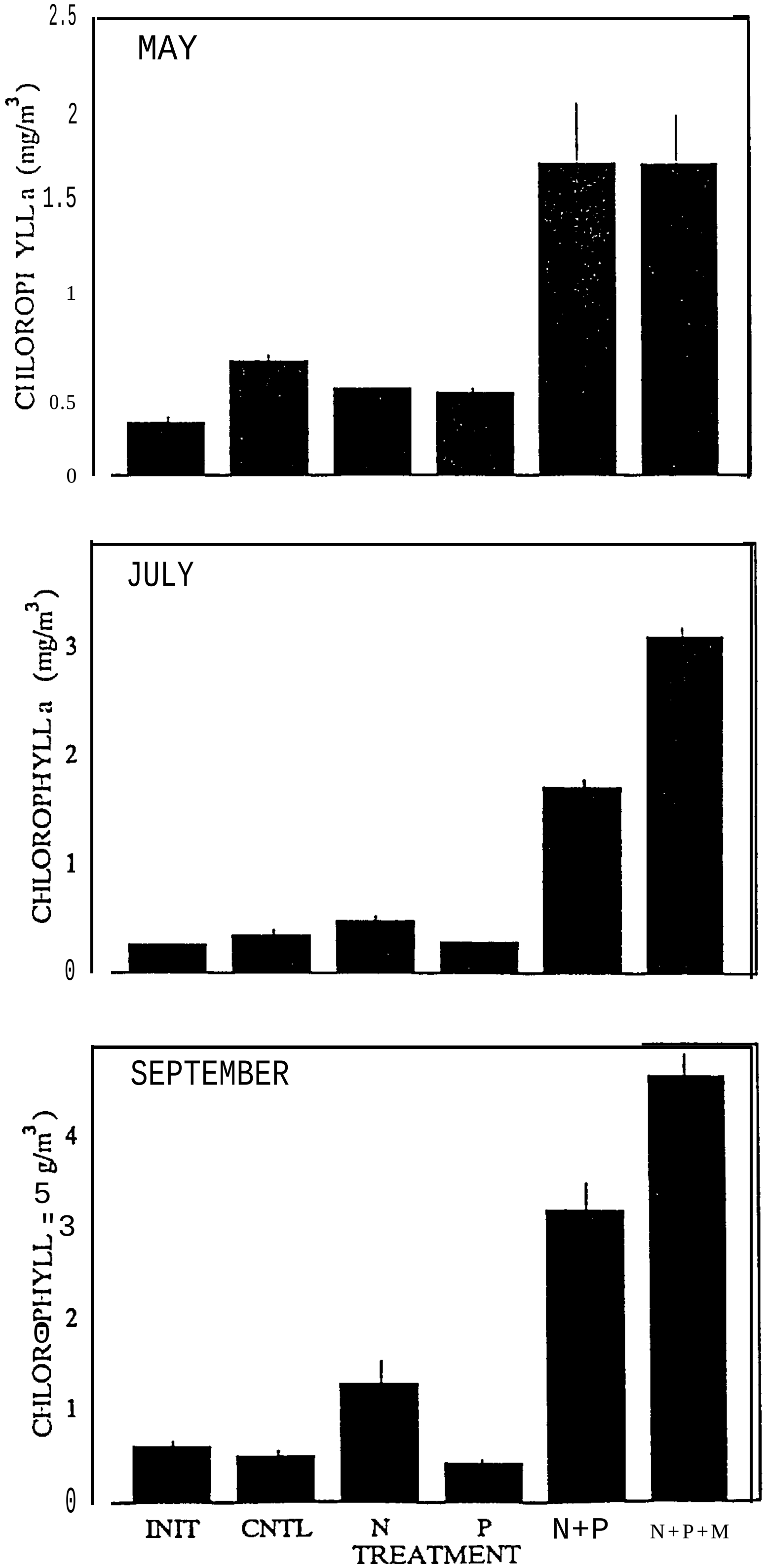

Fig. 7. Effects of additions of nitrogen (N), phosphorus ,(P), nitrogen + phosphorus (NP), and nitrogen + phosphorus + minor and micronutrients (NPM) on chlorophyll a production in Redfish Lake water during ***in vitro*** experiments.. Chlorophyll levels in the initial water samples (INIT), and in the control (CNTL) treatments are also shown. Experimental dates: 27 May - 1 June (5 days); 22 July - 2 Aug; 9-19 Sept.. Error bars show +1 SE of the mean.

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chlorophyll 500-680% above control levels during the 10-day incubation. Adding minor and micro-nutrients along with nitrogen and phosphorus significantly increased chlorophyll levels above that provided by N and P alone (Fig. 7).

Adding nitrogen and phosphorus at higher levels than in the standard experiments increased chlorophyll levels even more during the July in vitro experiment (Fig. 8). After 5 days chlorophyll levels in all the nutrient treatments were above control levels, but there were no significant differences between treatments at 1X, 2X and 4X the normal nutrient additions. After 10 days, however, treatments receiving two-times the nutrients had approximately twice as much chlorophyll (3.1 mg/m^3) as did the normal 1X treatment. In the treatment receiving 4-times the normal nutrient addition, chlorophyll levels were unexplainably lower than in the 2X treatment.

Discussion

The experimental results, combined with descriptive information on the lakes (Chapter 1), demonstrated that phytoplankton populations in the Sawtooth Valley lakes were severely nutrient-limited. Chlorophyll a levels in the lakes were often below 0.5 mg/m^3, indicating that they were highly oligotrophic (Wetzel 1983). Additions of nitrogen and phosphorus frequently increased chlorophyll levels to 4 mg/m^3 or more during the 10-day bioassays (Fig. 3). The in situ experiments indicated that nutrient

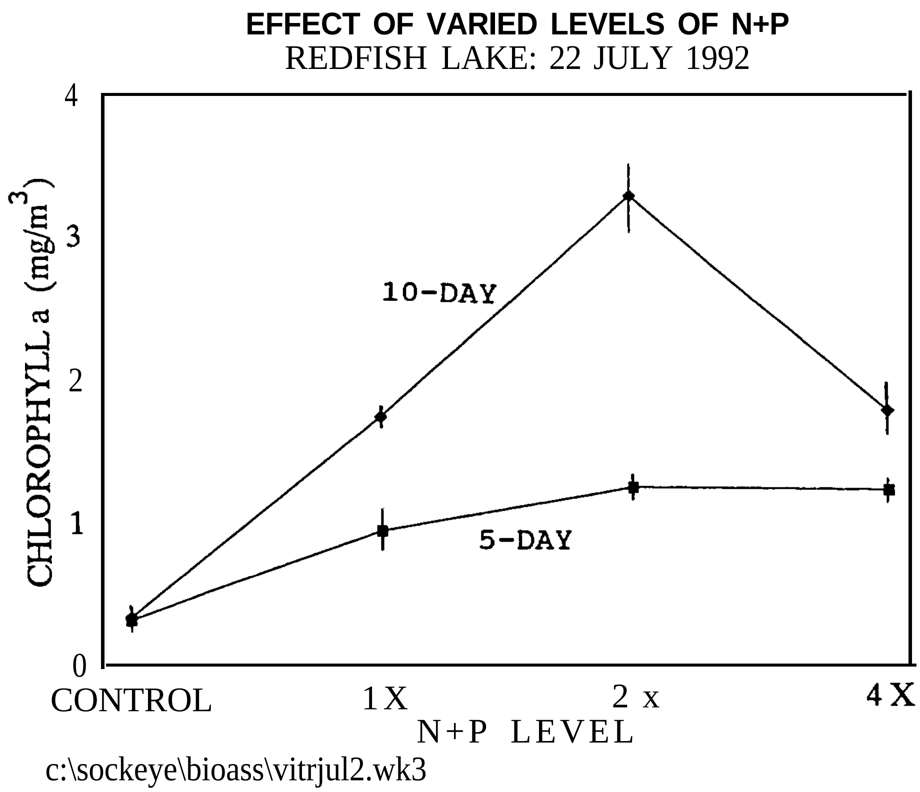

Fig. 8. Effects of increasing nutrient addition levels on chlorophyll a concentrations in Redfish Lake water tested during the July 1992 in ***vitro*** bioassay. Results after 5 and 10-day incubations are shown. The base nutrient addition (1X) was 0.34 μM N and 0.02 μM P. Error bars show $\pm$ 1 SE of the mean.

additions may stimulate phytoplankton more during midsummer than in the spring or fall (Fig. 4). This may be the result of somewhat lower available nutrients during midsummer (Appendix 4), or that epilimnetic temperatures were highest then (Table 4), permitting a faster algal response to the added nutrients.

The bioassays demonstrated that both nitrogen and phosphorus co-limited algal production in lakes. Phosphorus additions alone never significantly stimulated algal growth, whereas nitrogen sometimes enhanced chlorophyll levels moderately, particularly later in the season (Fig. 7). When both nutrients were added together, however, chlorophyll levels increased 500-2200% (Fig. 7, 4). Thus the widespread view that phosphorus alone limits algal growth in lakes (Schindler 1974) is not applicable to the Sawtooth Valley systems. A recent review of bioassay results from temperate lakes suggests, in fact, that nitrogen limits phytoplankton growth nearly as frequently as does phosphorus (Elser et al. 1990).

In our experiments, the minor- and micro-nutrient mixture, when added with N and P, frequently provided additional algal growth (Fig. 4, 7), suggesting that one or more of these may limit phytoplankton production. One of the "minor" nutrients added in the mixture was silicate, which is used by diatoms to synthesize their frustules. Diatoms, in fact, responded very strongly to the NPM treatment (Fig. 5), perhaps as the result of the silicate. However, the chlorococcales were also strongly enhanced by the mixture, indicating that some additional micro-nutrient could also have been limiting the total phytoplankton assemblage. It seems unlikely that micro-nutrients alone currently exert much control on the phytoplankton assemblage, because the NP additions always indicated that those macro-nutrients were controlling algal growth. If, however, the lakes are fertilized with nitrogen and phosphorus to alleviate this deficiency, some of the minor and/or micro-nutrients might then become limiting. We intend to monitor this effect during 1993 in limnocorral experiments.

In our experiments, zooplankton grazing apparently had a minimal effect on the phytoplankton populations (Fig. 4). A lack of grazing depression is not surprising, given the extraordinarily low biomass of zooplankton which ranged from 10-60 $\mu g/L$ in the lakes (Chapter 1). Median grazing rates of crustacean zooplankton are near 0.4 $ml \cdot \mu g^{-1} \cdot day^{-1}$ (Peters 1984), so that total grazing pressure should have been approximately 4-24 $ml \cdot L^{-1} \cdot day^{-1}$. Although species-specific grazing rates may vary and change these values somewhat, it appears that zooplankton grazed only about 0.4 - 2.4% of the water per day in the lakes, and perhaps $6\% \cdot day^{-1}$ in the treatments where we enhanced the zooplankton population 3-times over ambient levels. Phytoplankton mortality due to grazing was probably extremely low in both the lake and the experiments.

The occasional <u>enhancement</u> of algal populations by zooplankton additions in some experiments (Fig. 4) is more difficult to explain. Zooplankton additions may have stimulated phytoplankton production by increasing nutrient cycling or by boosting the overall nutrient levels in the cubetainers. Phytoplankton stimulation has been noted when fish are added to experimental systems and subsequently die and release nutrients (Threlkeld 1987). Some zooplankton added to our experimental treatments may have died, decomposed, and stimulated the algae. Our results can be interpreted more clearly when all of our zooplankton samples from the bioassays are completely analyzed, but it is likely that zooplankton did not have a major impact on the algae.

Although we did not see any large zooplankton effects in our short-term treatments, it is likely that nutrient-enhanced phytoplankton populations would eventually stimulate zooplankton because the phytoplankton that bloomed in the nutrient treatments were small species that could easily be grazed by zooplankton. In most fertilization studies on oligotrophic lakes, researchers have found that increased primary production is efficiently moved up the food web so that zooplankton and fish abundance frequently increase as much or more than do the phytoplankton (LeBrasseur et al. 1978; Hyatt and Stockner 1985; Kyle et al., In Press; C.R. Goldman, personal communication).

In practice, it appears that the phytoplankton production in the Sawtooth Valley lakes can easily be increased by fertilization, as has been done in Alaskan and Canadian sockeye systems (Hardy et al. 1986; Stockner 1987; Kyle et al. In Press). In these applications nitrogen and phosphorus are added in a ratio to insure that nitrogen is present in adequate amounts so that blooms of nuisance nitrogen-fixing cyanobacteria do not develop. The graded <u>in vitro</u> bioassays (Fig. 8) showed that we could expect varying increases in productivity dependent on the amounts of nitrogen and phosphorus added.

How much, then, should the lakes be fertilized? Answering this question will involve balancing the need to stimulate productivity to protect the endangered sockeye salmon, with the need to protect the aesthetic qualities of these important scenic lakes. It should be possible, however, to significantly increase lake productivity and still maintain water clarity within the ranges currently found in the lakes. For example, it might be desirable to fertilize the lake during summer stratification when chlorophyll levels are low, and when the algae appear to be most nutrient-limited. If fertilization levels are carefully chosen, we could likely limit summer chlorophyll levels to those found in the spring or fall. Alternatively, nutrients could be added to the metalimnions of the lakes where phytoplankton are also apparently nutrient-limited (Fig. 6). Metalimnetic fertilization has been demonstrated to enhance phytoplankton production in an oligotrophic Canadian lake (LeBrasseur et al. 1978).

In some of the lakes fertilization levels would need to be chosen conservatively to avoid hypolimnetic oxygen depletion. The low oxygen levels encountered in the deep water during 1992 was surprising, given the extreme water clarity of most of the lakes. It is likely that the deep-chlorophyll maxima present in each lake contributed substantially to productivity, because algal populations were abundant there and light was adequate for photosynthesis throughout much of the layer (Chapter 1, Fig. 6). In 1993 we will again monitor oxygen levels in the lakes, and study the contribution of the deep-chlorophyll maxima to lake productivity. The planned limnocorral experiments should also help us predict the degree of oxygen loss from the hypolimnions of the lakes under different fertilization regimes.

The short water residence times of 0.7 - 6.1 years in the lakes (Table 1) indicates that added fertilizers would be flushed from the systems relatively quickly. These residence times are probably maximal for the lakes because we measured discharges during 1992 at the end of a prolonged drought. The rapid flushing would allow us to stimulate the lakes at moderately high levels for several years to augment production of the endangered salmon, without risking long-term detrimental effects. Lakes with high flushing rates normally return quickly to former levels after fertilization is stopped (LeBrasseur et al. 1978).

An important consideration in determining the potential use of the Sawtooth Valley lakes for rearing sockeye is the role that spawned-out sockeye played in the nutrient budgets of the lakes. This is currently under investigation in our laboratory. If returning salmon provided a significant portion of the nutrient budgets, it would indicate that the lakes are now more oligotrophic than under pristine conditions. Consequently fertilization could return the lakes to a more natural state. Once salmon populations have been restored by this "jump start", and salmon passage problems solved on the Columbia and Snake Rivers, productivity in the system could be maintained by the constant supply of nutrients from returning adults.

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CHAPTER 3

FISHERIES ASSESSMENT OF THE ABUNDANCE AND TEMPORAL DISTRIBUTION OF SOCKEYE AND KOKANEE SALMON IN LAKES OF THE SAWTOOTH VALLEY

D. A. Beauchamp, P. E. Budy, W. A. Wurtsbaugh, H. Gross, C. Luecke, and S. Spaulding

Spawning and the freshwater rearing phase of the endangered Snake River stock of sockeye salmon Oncorhvnchus nerka occurs in the Sawtooth Valley Lakes, Idaho. Historical canning records indicated that this stock once produced an average spawning population of 20,000-40,000 adults, but water diversions, hydroelectric dams, interceptions in the Columbia River fisheries, and other habitat degradation have reduced the returning adult population to only a few spawners since 1990. Since sockeye salmon generally produce 500-4,000 eggs per female, and the eggs and young experience high mortality (Foerster 1968), small improvements in juvenile survivorship can potentially yield large increases in population abundance. Hence, an attractive way to enhance recovery of the population is to identify and quantify the processes which limit production or survivorship, and then evaluate the feasibility of improving these conditions.

The processes most likely to limit juvenile sockeye production while rearing in nursery lakes include the amount and quality of food available per juvenile and mortality from predation. The per capita food supply is a function of both the productivity of the lake and the number of inter- and intraspecific competitors available to exploit the food supply. The effect of predation depends on the number of juvenile sockeye salmon eaten relative to the size of the sockeye population in the lake. Predators can also have an indirect effect on the production of juvenile sockeye salmon by limiting access to their zooplankton prey. Eggers (1978) and Clark and Levy (1988) presented evidence that juvenile sockeye salmon performed die1 vertical migrations as a way to feed in the upper zooplankton-rich water while minimizing the risk of predation by sight-feeding piscivores. Juvenile sockeye salmon limited feeding episodes to the twilight periods and reduced their daily ration when compared to the potential ration from feeding throughout the daylight and twilight hours.

Estimates of population abundance and temporal changes in distribution of juvenile sockeye salmon are critical elements in any evaluation of the carrying capacity of the lakes or the effect of predation on salmon production. In this paper we estimate the abundance of different size classes of sockeye/kokanee salmon in each of the Sawtooth Valley Lakes and to describe die1 changes in their distribution. We then examine distributional patterns among the lakes in relation to environmental factors and relative predator density.

Study Area

The Sawtooth Valley Lakes is located in the headwaters of the Salmon River in the Sawtooth National Recreational Area in central Idaho. The five study lakes, Redfish, Alturas, Pettit, Stanley, and Yellow Belly, are small to medium-sized, dimictic, oligotrophic lakes (Table 1) with summer epilimnetic temperatures of 14-18° C. Fish were removed from Yellow Belly Lake with toxicants in 1988 then restocked with cutthroat trout Oncorhvnchus clarki with the intention of maintaining the population as brood stock. Thus Yellow Belly Lake provides an interesting contrast from the fish assemblages in the other four lakes which include: lake trout Salvelinus namavcush, bull trout

Table 1. Limnological features of the five study lakes in the Sawtooth Valley, Idaho.

Lake	Area (km2)	Depths (m)		
		Maximum	Mean	Average Secchi
Redfish	6.17	92	41	13.6
Alturas	3.38	53	33	13.0
Pettit	1.63	52	28	15.0
Stanley	0.73	26	16	7.9
Yellow Belly	0.80	26	13	12.3

S. confluentus, brook trout S. fontinalis, rainbow trout Oncorhvnchus mvkiss, kokanee/sockeye salmon 0. nerka, mountain whitefish Prosooium williamsoni, northern squawfish Ptvchocheilus oreqonensis, redside shiners Richardson& balteatus, and mountain suckers Catostomus platyrhynchus.

Methods

We measured nocturnal abundance and examined the die1 vertical distribution patterns of different-sized targets using dual-beam hydroacoustic techniques (Burczynski and Johnson 1986). Data were gathered using a BioSonics Model 105 scientific echosounder with a 420 kHz dual beam (6^{o}, 15^{o}) transducer in a fin towed 0.75 m deep off the port bow of a 7 m boat. Data were simultaneously recorded directly into computer files using ESP 2.0 dual beam signal processing software, and through a BioSonics model 171 recording interface onto digital audio tapes (DAT). Data were sampled at 2 pings s^{-1} traveling at 4-6 m s^{-1}. We used a 0.4 ms pulse width and receiver sensitivity gain of 12 decibels (dB). We sampled 5-14 transects across each lake during moonless nights on September 24-26, 1992 (Figure l), and 2-9 transects during the day and dusk periods on Redfish, Alturas, and Yellow Belly Lakes. Temperature and dissolved oxygen profiles were measured during the surveys on each lake.

We analyzed fish densities by depth from three size classes: -59 to -51 dB (age 0+ sockeye/kokanee salmon; approximately 3-8 cm total length), -51 to -43 dB (age l+ sockeye/kokanee salmon 8-17 cm), and -43 to -30 dB (older kokanees and piscivorous fishes

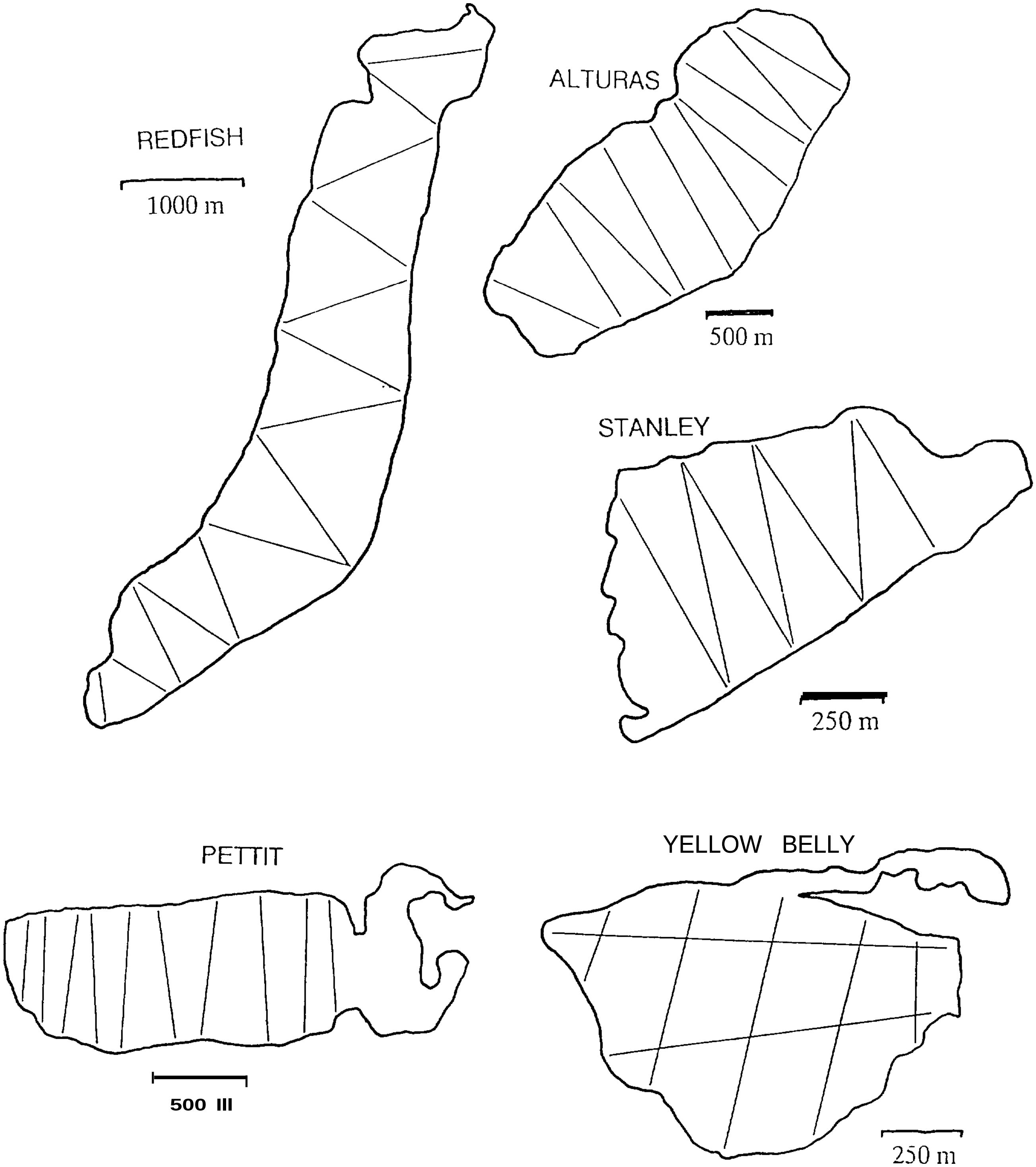

Figure 1. Map of the study lakes in the Sawtooth Valley indicating the hydroacoustic transects from night surveys in all but Yellow Belly Lake where the daytime transects were more appropriate. Note the different distance scales for each lake.

> 17 cm total length; Dahm et al. 1985; Love 1977). Only the echoes within 4° of the acoustic axis and that met the single echo criteria of the ESP software (signal 0.03-6.99 V_{rms}; 0.4-0.52 ms echo pulse width at half signal amplitude) were included in the analysis. Analyses were stratified by 5-m depth intervals over O-30 m, 10-m intervals over 30-60 m, and a 60-90 m interval where applicable.

Midwater trawl samples were taken on the same nights as the hydroacoustic surveys to verify the species and size composition of the acoustic targets. Idaho Department of Fish and Game trawled along the longitudinal axis of each lake except Yellow Belly Lake which was inaccessible to the trawling boat. The midwater otter trawl had a cross-sectional mouth area of 9.29 m^2, 3 mm knotless mesh in the cod end, and was towed at 1.0 m s^{-1} in steps (generally 5 min per step) through the range of depths containing targets (see Reiman 1992 for details).

The potential predator and competitor communities were sampled with sinking horizontal gill nets in Alturas, Pettit, and Stanley Lakes in mid-September 1992. Redfish Lake was sampled with gill nets in July 1991, and Yellow Belly Lake in June 1992. The 37 m x 2 m variable mesh gill nets contained panels of 76 mm, 102 mm, 128 mm, 152 mm, 178 mm, and 204 mm stretch mesh sizes. Six to eight nets were set for 24 h in two quadrants of each lake one night, then reset in the two remaining quadrants the following night. In each quadrant, nets were set perpendicular to shore in three depth intervals: 2-10 m, lo-20 m, and >20 m. An additional net was occasionally set parallel to shore in one of these depth intervals. The catch per hour per net was recorded for each species. Lengths and weights were measured and stomach contents were removed for future analysis.

Results

Species and Size Composition

The night midwater trawls caught 494 sockeye/kokanee salmon (40-220 mm fork length) and only 7 redside shiners (80-90 mm), suggesting that the nocturnal limnetic community was dominated by 0. *nerka* (Table 2). Three year classes corresponding with modal lengths of 6 cm, 12 cm, and 20 cm were encountered in trawl samples in Redfish Lake, whereas single length modes of 20 cm and 12 cm were found at Pettit Lake and Alturas Lake, respectively. Modes in the dual beam target strength frequency distribution roughly corresponded to length frequency modes from the midwater trawl samples. However, the acoustic target strength distribution revealed additional size modes (Figure 2) suggesting that other year classes were present but not detected due to low trawl catches in some lakes. For instance, only 10 and 18 sockeye/kokanee salmon were captured in Stanley and Pettit Lakes, respectively, whereas 78 and 479 targets from -59 to -40 dB were detected acoustically in these lakes.

We used littoral and lake-slope gill net catch per unit effort as an index of potential competition and predation risk for juvenile sockeye/kokanee salmon in each lake (Figure 3). Although catches in these nets do not necessarily mean that these fish use the limnetic zone, these data are helpful for interpreting patterns in the hydroacoustic data. Other limnetic

Table 2. Summary of midwater trawling catches in August and September 1992.

Trawl Depth (m)	N	Sockeye per 5-min Trawl	2 SE	Shiners per 5-min Trawl	2 SE
		Redfish Lake			
4-29	4	0.61	0.28	0.00	0.00
12-29	4	1.35	0.39	0.00	0.00
12-16	2	0.78	0.78	0.19	0.38
22-24	2	2.00	3.33	0.00	0.00
		Alturas Lake			
3-24	1	5.68	---	0.00	---
12-30	6	5.60	1.76	0.00	0.00
17-18	1	0.17	---	0.00	---
24-24	1	7.50	---	0.00	---
28-28	1	13.33	---	0.00	---
30-30	1	11.67	---	0.00	---
		Pettit Lake			
10-12	1	0.00	---	1.25	---
12-20	2	0.56	1.11	0.00	0.00
18-20	1	0.70	---	0.00	---
		Stanley Lake			
16	1	2.00	---	1.00	---
12	4	1.96	1.77	0.97	1.36

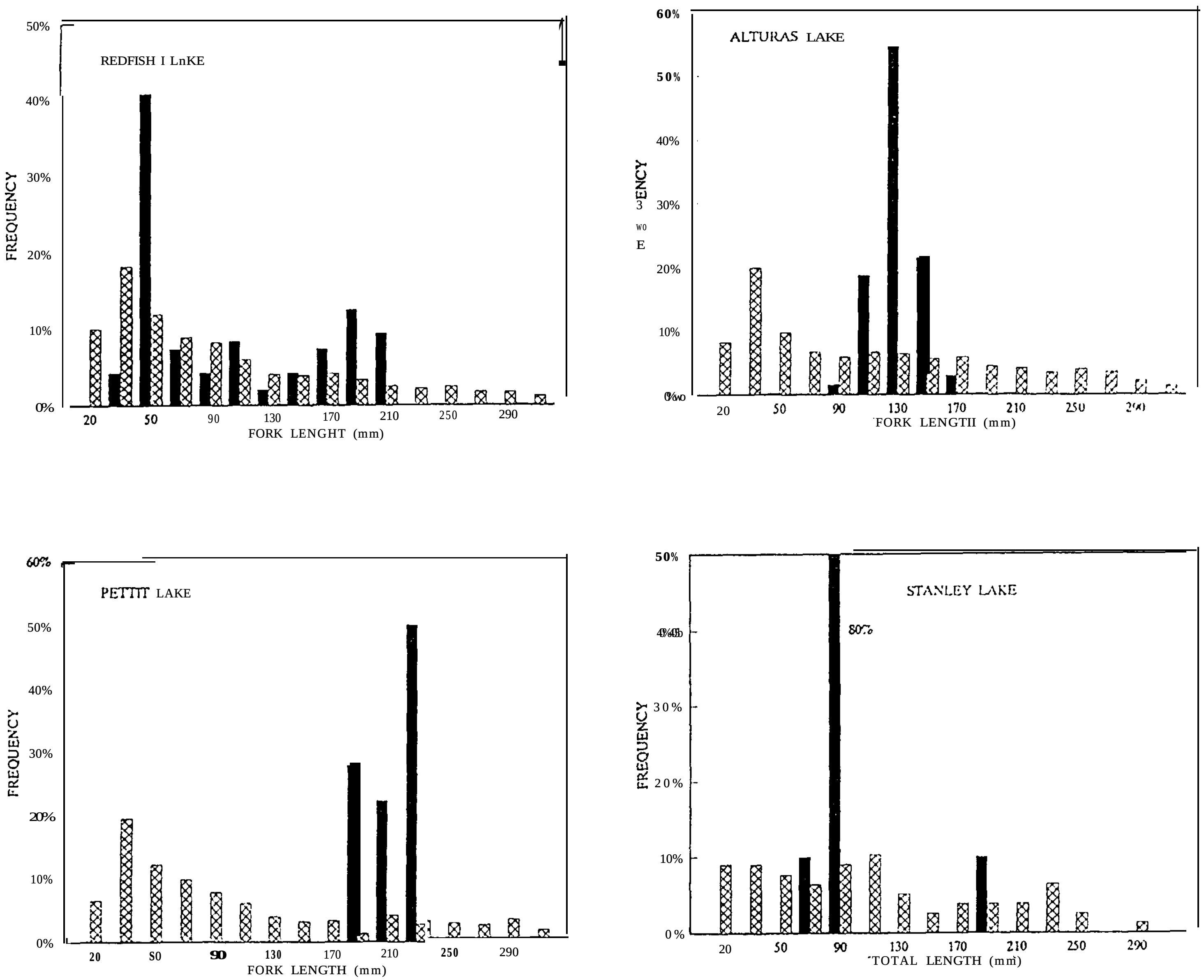

Figure 2. Length frequency histograms of sockeye/kokanee salmon from midwater trawl catches (dark bars) and dual-beam estimates of target strength that were converted to fish length (cross-hatched bars) using regression equations of Love (1977) and Dahm et al. (1985).

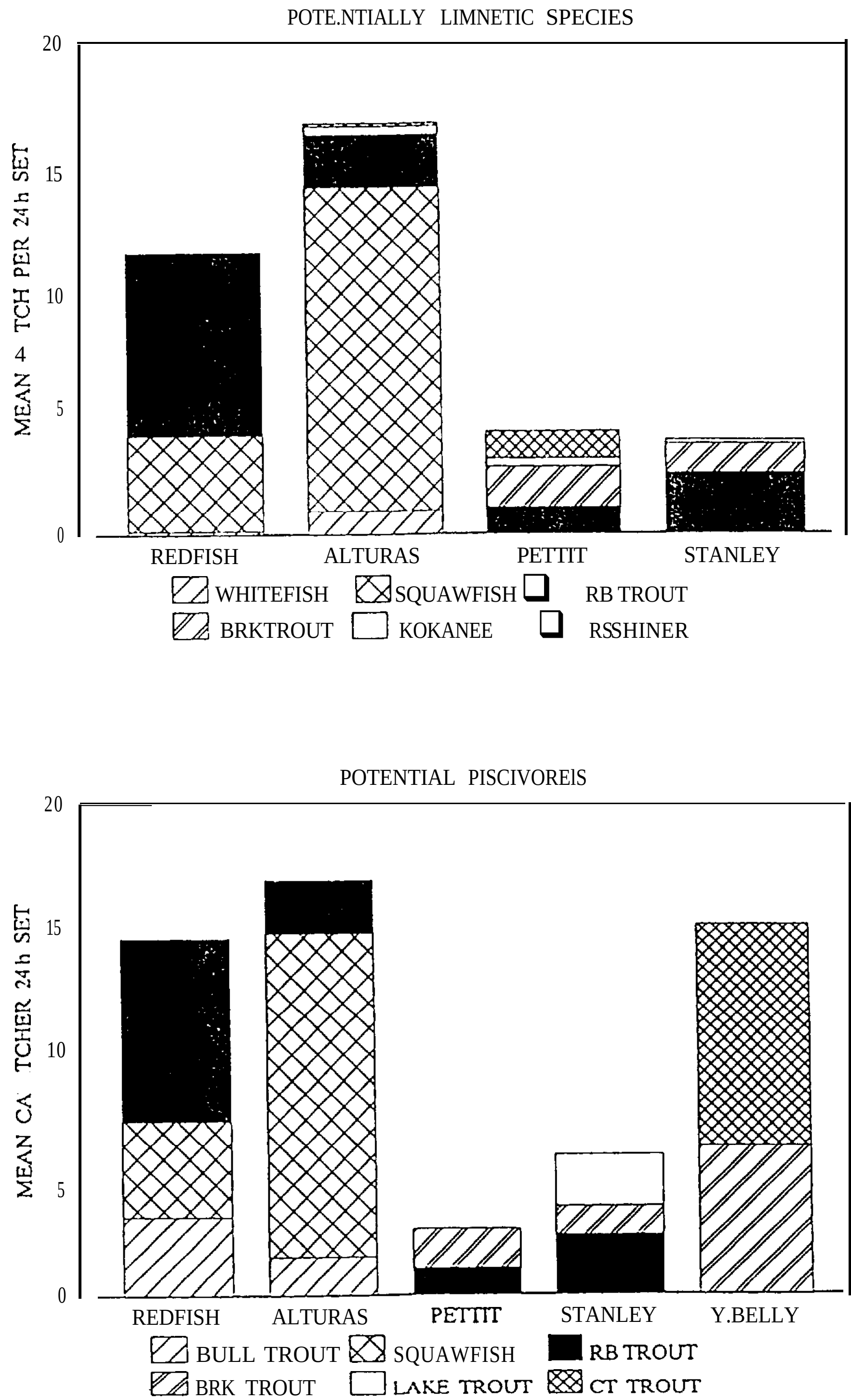

Figure 3. Nearshore gill net catch per unit effort of potentially pelagic fish (top panel) and potential piscivores (bottom panel).

species might compete for zooplankton. Also, if other species were mixed with limnetic sockeye/kokanee salmon, they must be proportionally allocated across the hydroacoustic estimates of fish density. The relative density of potential piscivores could alter die1 distribution patterns of juvenile sockeye/kokanee salmon. Redfish and Alturas Lakes contained relatively higher densities of rainbow trout and northern squawfish than the other lakes (Figure 3). These species could occupy the upper limnetic zone (O-20 m; Figure 4) but would be invulnerable to the midwater trawl. Stanley and Pettit Lakes contained lower densities of rainbow trout, brook trout, and redside shiners (in Pettit Lake only) that were concentrated in the upper depth strata (Figure 4).

Die1 Patterns in Horizontal and Vertical Distribution

The die1 horizontal and vertical distribution of targets varied among lakes and by fish size. In Redfish Lake, few limnetic targets were encountered during midday, and most targets were associated with the sloping perimeter of the lake; more fish entered the mid and upper water column and dispersed away from the slope at dusk; midwater target densities peaked at night (Figure 5). The smallest fish (3-7 cm) concentrated in warmer epilimnetic waters (O-5 m deep) during dusk and night, whereas larger targets remained in the metalimnion (l0-25 m; Figure 6). Limnetic densities were higher and less associated with the perimeter slope in Alturas Lake (Figure 5). All sizes of targets were most dense at O-5 m during the day in Alturas Lake and moved progressively deeper at dusk and night (Figure 6). The high

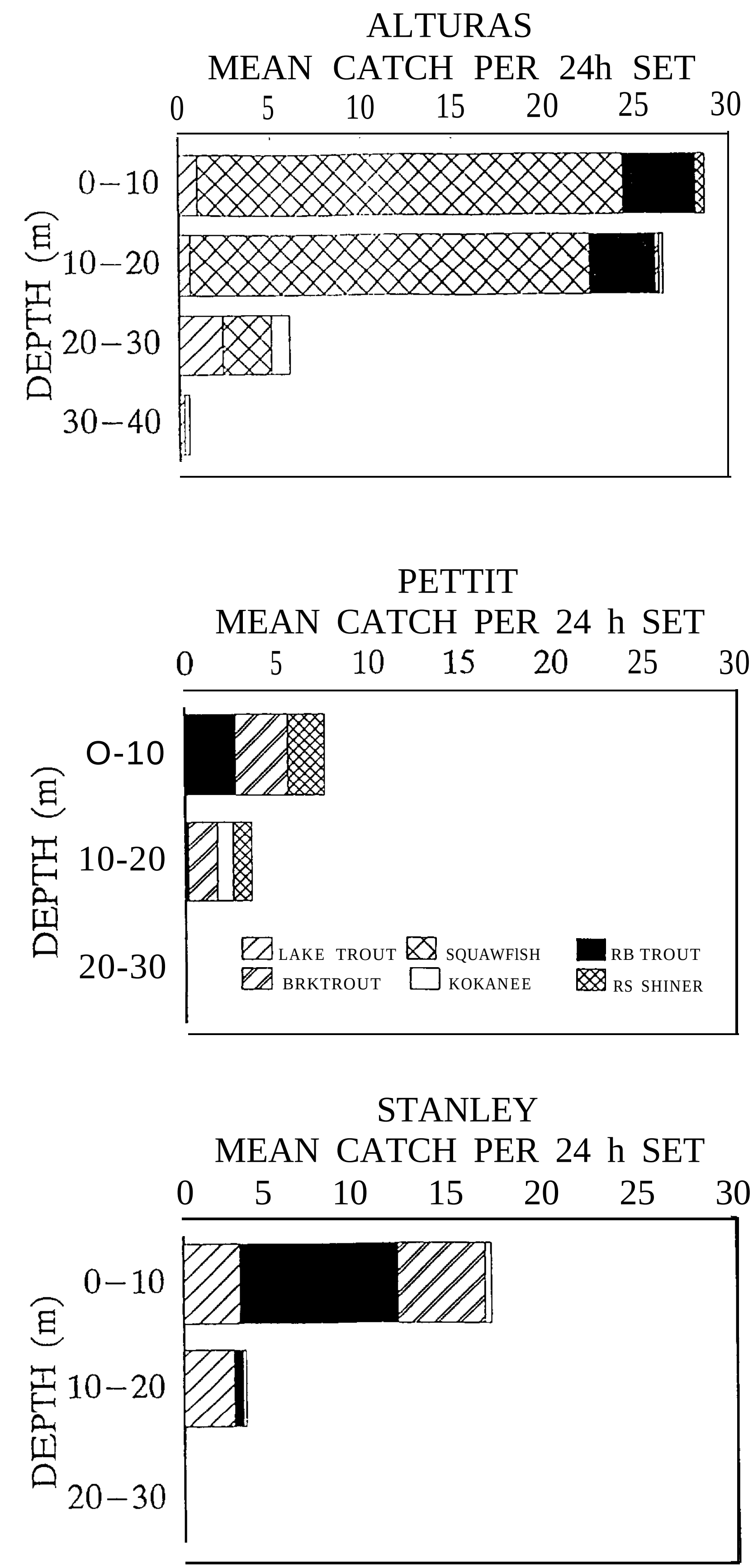

Figure 4. Depth distribution of species caught in nearshore gill nets set in Alturas, Pettit, and Stanley Lakes during August-September. Depth-specific catch data were not available from gill nets set in Redfish Lake and Yellow Belly Lakes.

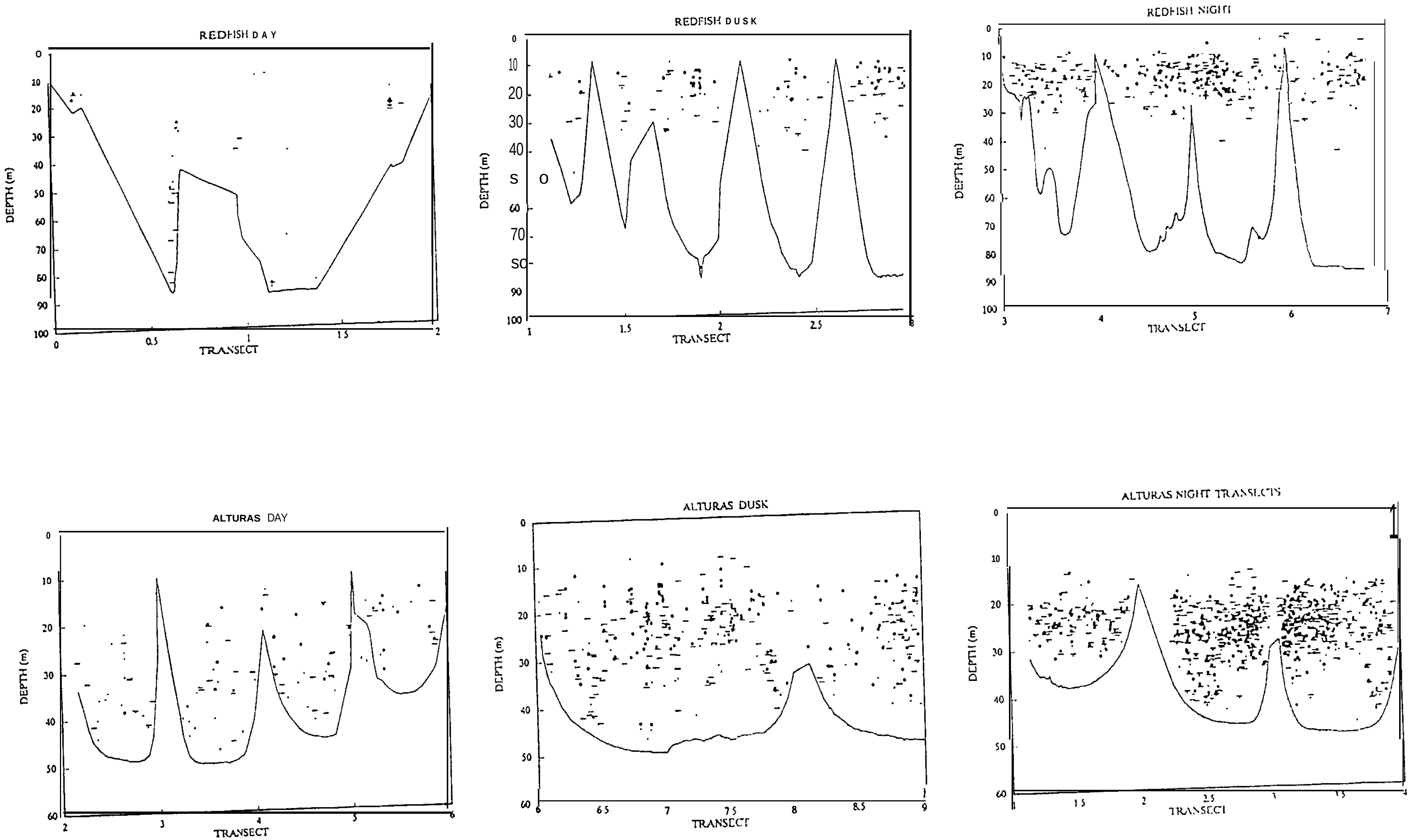

Figure 5. Computer-generated echograms showing the vertical and horizontal distribution of targets during day, dusk, and night periods in Redfish and Alturas Lakes. The size of the symbols indicate the size of fish: (*) $\geq$ 18 cm fish, (-) for 7-18 cm fish, and (.) for 3-7 cm fish.

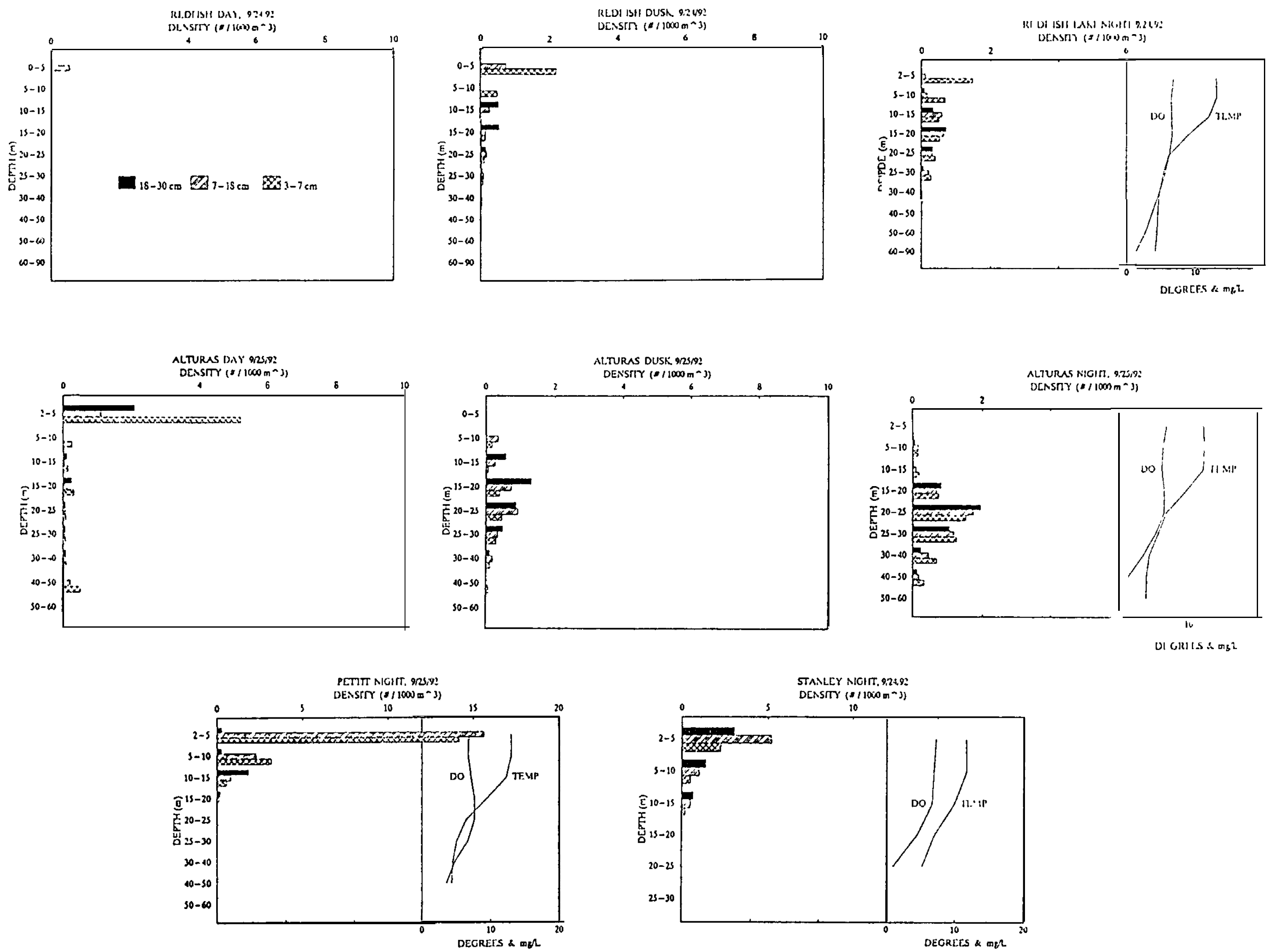

Figure 6. Temperature and dissolved oxygen profiles and the limnetic density of three size classes of fish by depth for the study lakes containing sockeye/kokanee salmon. Day, dusk and night periods are presented for Redfish and Alturas Lake; but only night patterns are shown for Pettit and Stanley Lake;.

nighttime densities of fish in the shallow strata of Pettit Lake (Figure 6) were predominantly redside shiners; they were clearly identified in the beam of the boat's spotlight, and these observations were supported by midwater trawl (Table 2) and gill net catches (Figure 4). Nighttime densities of all fish sizes decreased with depth in Stanley Lake (Figure 6). Although fish densities varied among nighttime transects within lakes, only Pettit Lake exhibited prominent differences among areas of the lake. Densities along transects 8-10 averaged lo-fold higher than elsewhere in the lake (Figure 7; Kruskal-Wallis test, $p < 0.05$). In contrast to the lakes containing sockeye/kokanee salmon, limnetic fish densities in Yellow Belly Lake were highest during the day in the upper epilimnion (O-5 m), declined at dusk, and were nearly imperceptible at night (Figure 8).

Population Abundance

The abundances and densities of limnetic fish in each of the study lakes are presented in Table 3. When these estimates were adjusted for the depth-specific species compositions observed in the midwater trawls, the sockeye/kokanee salmon estimates (2 SE) were 188,000 (113,000) for Redfish Lake, 144,000 (56,000) for Alturas Lake, 19,000 (13,000) for Pettit Lake, and 33,000 (28,000) for Stanley Lake (Table 4). The abundance of limnetic cutthroat trout and brook trout in Yellow Belly Lake was estimated from the daytime survey as 32,000 (50,000).

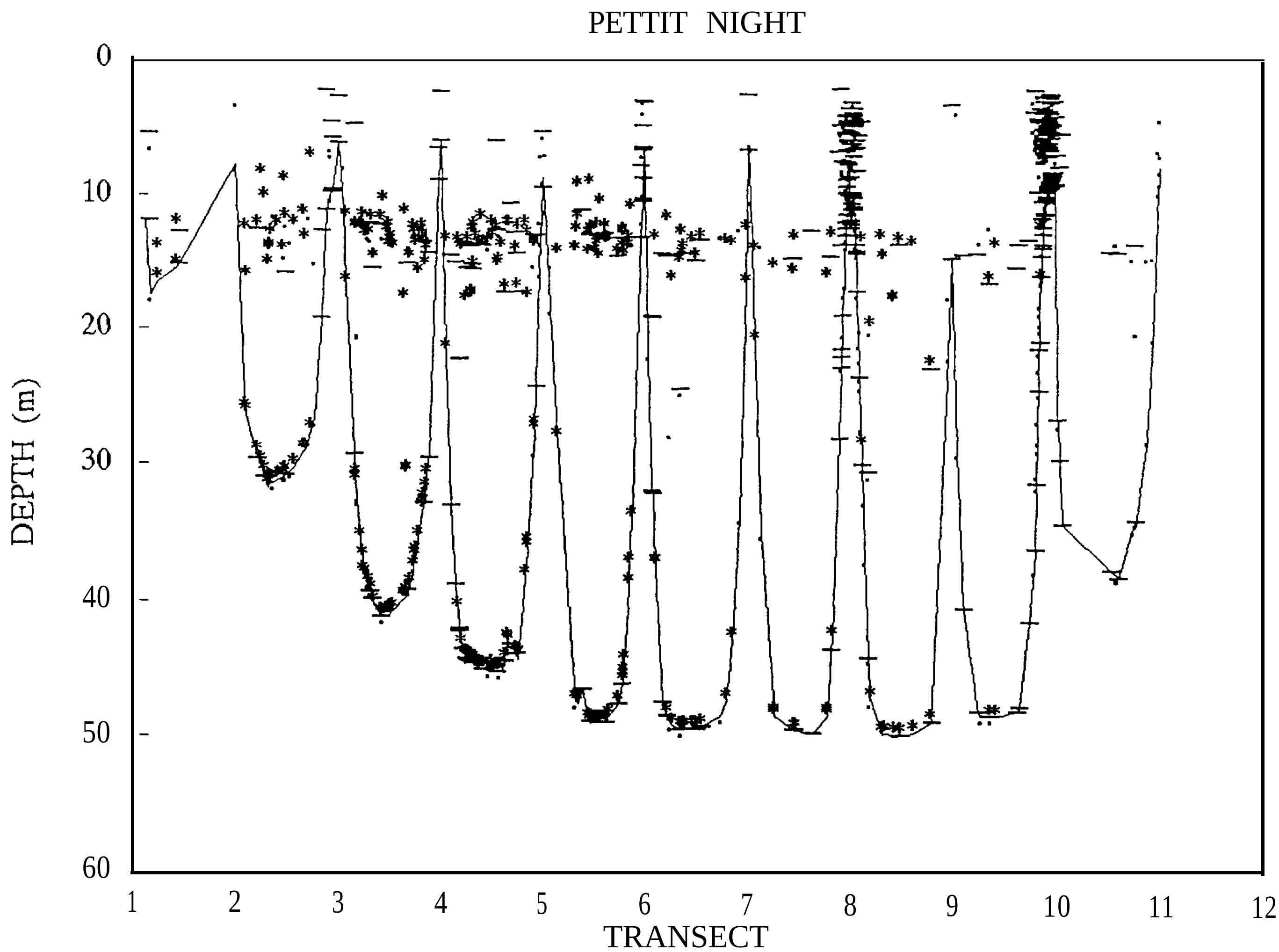

Figure 7. Computer-generated echogram of the night transects surveyed in Pettit Lake. The unusually high density of shallow, nearshore targets at the beginning of transects 8 and 10 are attributed to redside shiner aggregations.

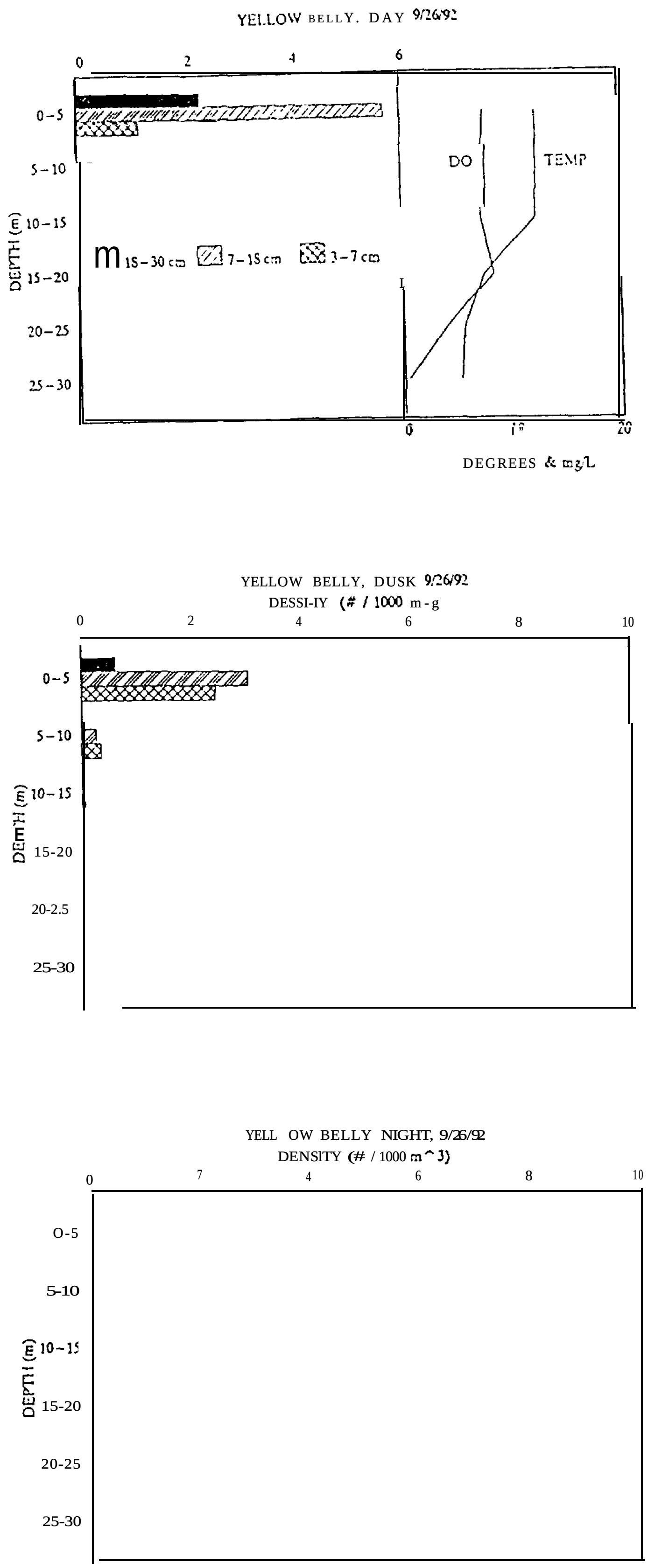

Figure 8. Temperature and dissolved oxygen profiles and the limnetic density of three size classes of fish by depth for Yellow Belly Lake, which contains predominantly cutthroat and brook trout and sockeye/kokanee salmon are absent.

Table 3. The estimated abundance and density of all limnetic fish by size in each of the five study lakes. Estimates were based on nighttime hydroacoustic surveys for all but Yellow Belly Lake where daylight surveys were used.

REDFISH LAKE	ESTIMATED SIZE 18-30 cm	7-18 cm	3-7 cm	TOTAL
ABUNDANCE	39,661	52,839	107,116	199,617
2 SE	15,034	25,768	75,610	116,412
#/1000 m^3	0.16	0.21	0.43	0.79
#/ha	64	86	174	324

ALTURAS LAKE	SIZE 18-30 cm	7-18 cm	3-7 cm	TOTAL
ABUNDANCE	44,203	47,676	51,982	143,860
2 SE	14,940	17,035	24,471	56,446
#/1000 m^3	0.40	0.43	0.47	1.31
#/ha	131	141	154	426

PETTIT LAKE	SIZE 18-30 cm	7-18 cm	3-7 cm	TOTAL
ABUNDANCE	15,353	125,586	119,566	260,505
2 SE	11,334	111,892	101,170	224,397
#/1000 m^3	0.34	2.78	2.65	5.78
#/ha	94	770	734	1598

STANLEY LAKE	SIZE 18-30 cm	7-18 cm	3-7 cm	TOTAL
ABUNDANCE	14,123	19,203	8,456	41,782
2 SE	8,039	21,055	8,371	37,465
#/1000 m^3	1.35	1.03	0.81	3.98
#/ha	193	263	116	572

Table 3. continued

YELLOW BELLY	ESTIMATED SIZE			
	18-30 cm	7-18 cm	3-7 cm	TOTAL
NIGHTTIME				
ABUNDANCE	134	0	0	134
#/1000 m^3	0.01	0.00	0.00	0.01
#/ha	2	0	0	2
DAYTIME				
ABUNDANCE	7,752	20,180	4,276	32,208
2 SE	14,927	28,619	6,389	49,935
#/1000 m^3	0.77	2.00	0.42	3.19
#/ha	97	252	53	403

Table 4. The abundance and density of the sockeye/kokanee fraction of limnetic fish estimated from nighttime hydroacoustic and midwater trawl surveys in Redfish, Alturas, Pettit, and Stanley Lakes.

REDFISH LAKE	ESTIMATED SIZE 18-30 cm	7-18 cm	3-7 cm	TOTAL
ABUNDANCE	39,661	46,545	101,839	188,045
2 SE	15,034	24,008	73,824	112,866
#/l000 m^3	0.16	0.19	0.40	0.75
#/ha	64	75	165	305

ALTURAS LAKE	SIZE 18-30 cm	7-18 cm	3-7 cm	TOTAL
ABUNDANCE	44,203	47,676	51,982	143,860
2 SE	14,940	17,035	24,471	56,446
#/l000 m^3	0.40	0.43	0.47	1.31
#/ha	131	141	154	426

PETTIT LAKE	SIZE 18-30 cm	7-18 cm	3-7 cm	TOTAL
ABUNDANCE	15,353	2,076	1,315	18,743
2 SE	11,334	966	778	13,078
#/1000 m^3	0.34	0.05	0.03	0.42
#/ha	94	13	8	115

STANLEY LAKE	SIZE 18-30 cm	7-18 cm	3-7 cm	TOTAL
ABUNDANCE	14,123	12,824	5,647	32,593
2 SE	8,039	14,061	5,590	27; 690
#/l000 m^3	1.35	1.22	0.54	3.11
#/ha	193	176	77	446

Discussion

The efforts to rehabilitate the Snake River sockeye salmon stock requires a quantitative assessment of the distribution and abundance of sockeye/kokanee salmon and sympatric species in their nursery lakes. From this assessment, researchers should then be able to interpret the behavior and dynamics of juvenile sockeye salmon within the context of the spatial-temporal changes in density of potential competitors, predators, and prey.

Sockeye/kokanee salmon were generally deep or absent from the water column during the day, but dispersed into the metalimnion during the dusk and dark hours. This pattern is consistent with observations from other populations in the Pacific Northwest (Narver 1970, Woodey 1972, Eggers 1978, Clark and Levy 1988, Levy 1990). Daytime concentrations of other fishes in shallower waters corresponded with the presence of rainbow trout, brook trout, or cutthroat trout, and shallow nighttime concentrations corresponded with the presence of redside shiners.

Die1 changes in the species composition of the limnetic community could influence our ability to accurately assess the abundance and size distribution of sockeye/kokanee in these lakes, but information gained from complementary sampling by midwater trawls, gill nets, and hydroacoustics minimized this uncertainty. Nighttime midwater trawling indicated that sockeye/kokanee salmon were the predominant nocturnal species in most of the study lakes. Redside shiners in Pettit Lake were an exception to this; they were detected visually, caught in shallow midwater trawls and gill nets, and were removed from the estimate of salmon abundance. The strong association of shallow acoustic targets (7-18 cm fish) with the shore at the beginning of transects 8 and 10 in Pettit Lake (Figure 7) further supports our contention that these targets were predominantly redside shiners rather than salmon.

Due to their shallow distribution, tremendous errors could result if the redside shiners were not removed from the hydroacoustic abundance estimate. The the volume of water sampled by the acoustic cone in shallow strata is quite small relative to deeper strata (the cross-sectional area of the cone increases as the square of distance [depth] from the transducer); hence large multipliers are needed to expand fish density from sample volumes to an abundance estimate for the entire volume of the shallowest stratum.

A similar phenomenom might explain the high daytime density of fish in the shallowest stratum of Alturas Lake. An inspection of the computer-generated echogram (Figure 5) does not reveal inordinately high densities of targets in the upper water column; instead small aggregations appear at the beginning of transects 3 and 5. In this case, the proximity of the acoustic targets to shore and the gill net data (Figure 4) suggest that rainbow trout and perhaps northern squawfish are the most likely culprits. We speculate that the daytime peak, dusk trough, and nighttime peak in limnetic abundance in Alturas Lake indicates a "changing of the guard" from daylight-crepuscular species (see Helfman 1981) to the crepuscular-nocturnal sockeye/kokanee salmon. The declining limnetic density of trout in Yellow Belly Lake from day to night demonstrates the pattern that occurs when no crepuscular-nocturnal species like sockeye salmon are available to fill the limnetic zone at night.

The presence of sympatric planktivorous fishes in the limnetic zone has implications for estimating the total consumption demand on the zooplankton resource by these potential competitors. Our ability to correctly estimate zooplanktivorous demand in time and space depends on an accurate assessment of all major consumers utilizing this resource. Rainbow trout and redside shiners in particular are facultative zooplanktivores. Rainbow trout tend to forage during daylight and crepuscular periods (Beauchamp 1990) whereas redside shiners (Johannes and Larkin 1961; W. Wurtsbaugh, unpublished data) and juvenile sockeye salmon generally feed most heavily during crepuscular or night hours (Narver 1970; Eggers 1978; Levy 1990). Juvenile sockeye salmon can feed on zooplankton at only 5-35% of their maximum efficiency at depths providing lO-100% of the surface light intensities under new moon conditions (0.005-0.0005 lux; Ali 1959). This corresponds with nocturnal feeding depths ranging from the surface to 18 m in Redfish Lake, 16 m in Alturas Lake, 14 m in Pettit Lake, and 8 m in Stanley Lake. Except for in Alturas Lake (and Yellow Belly Lake which has no salmon), most of the limnetic targets occupy depths at or above this sight-feeding threshold at night (see Figure 6). Rainbow trout can feed with maximum efficiency during the daytime and crepuscular periods. If zooplankton densities were reduced such that search time was increased under low light intensities, then sockeye/kokanee salmon could suffer reduced rations before the lower prey densities affected the rations of rainbow trout or other daylight-feeding plantivores.

The density and species composition of the limnetic fish assemblage varied among the Sawtooth Valley Lakes. Pettit Lake contained the highest density of limnetic fish, but had the lowest density of sockeye/kokanee salmon. Redfish Lake contained the lowest density of limnetic fish, and the second lowest density of sockeye/kokanee salmon. Stanley Lake contained the highest densities of sockeye/kokanee salmon and the second highest density of total limnetic fishes. The cutthroat and brook trout comprised the pelagic fish assemblage of Yellow Belly Lake, and limnetic densities were comparable to Stanley Lake. The density of limnetic fishes (324 ha^{-1}) in Redfish Lake was 22% higher in 1992 than in 1991, whereas densities in Alturas Lake in 1992 were only 36% of the 1991 densities.

This assessment of the abundance and die1 distribution of sockeye/kokanee salmon and sympatric limnetic species provides an important step toward quantifying the foodweb interactions in the Sawtooth Valley Lakes. Additional data are needed to describe the food habits of predators and prey in time and space and by body size and on the abundance of the large piscivores (e.g. lake trout and bull trout) which are not available to hydroacoustic assessment techniques.

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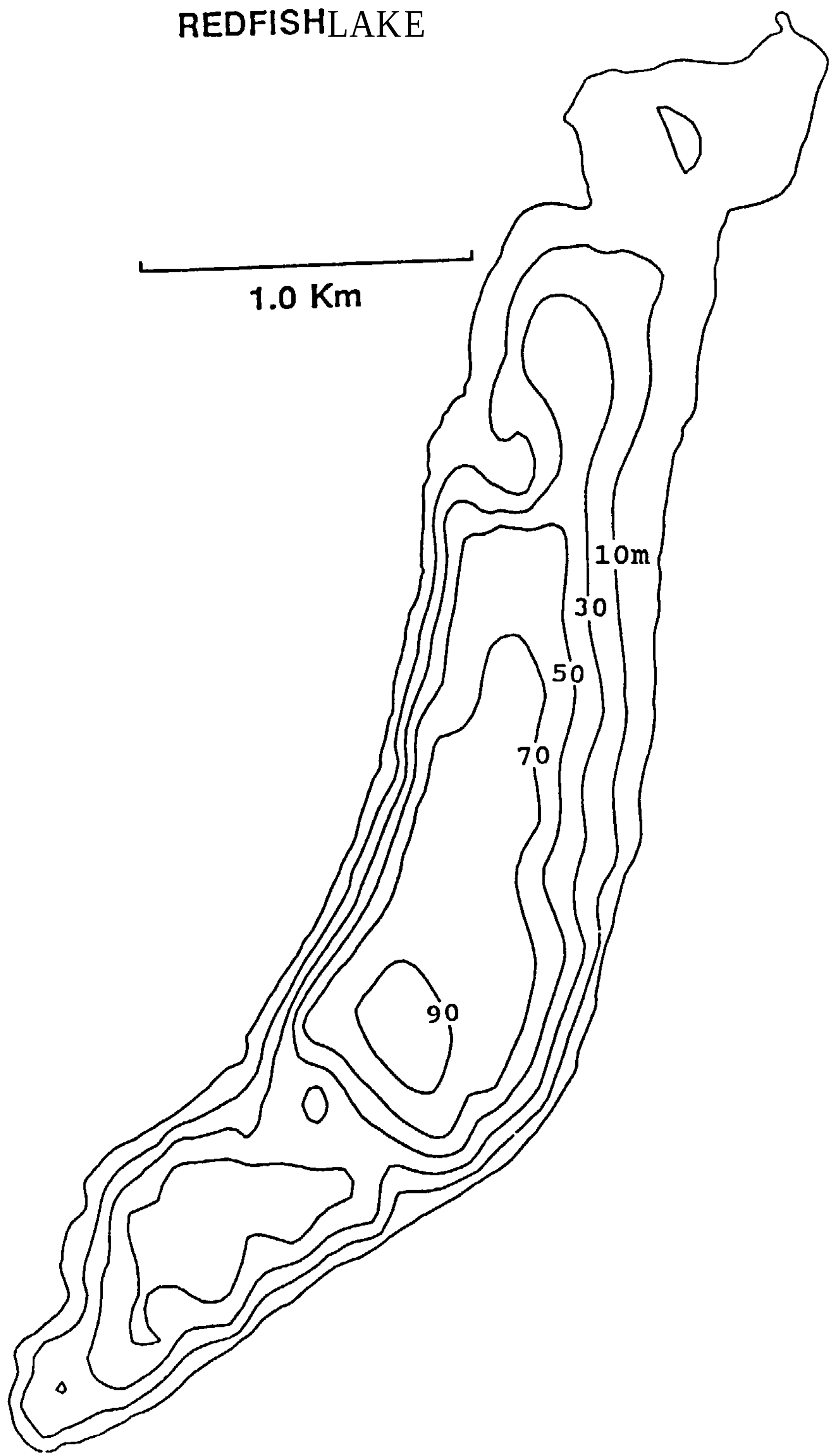
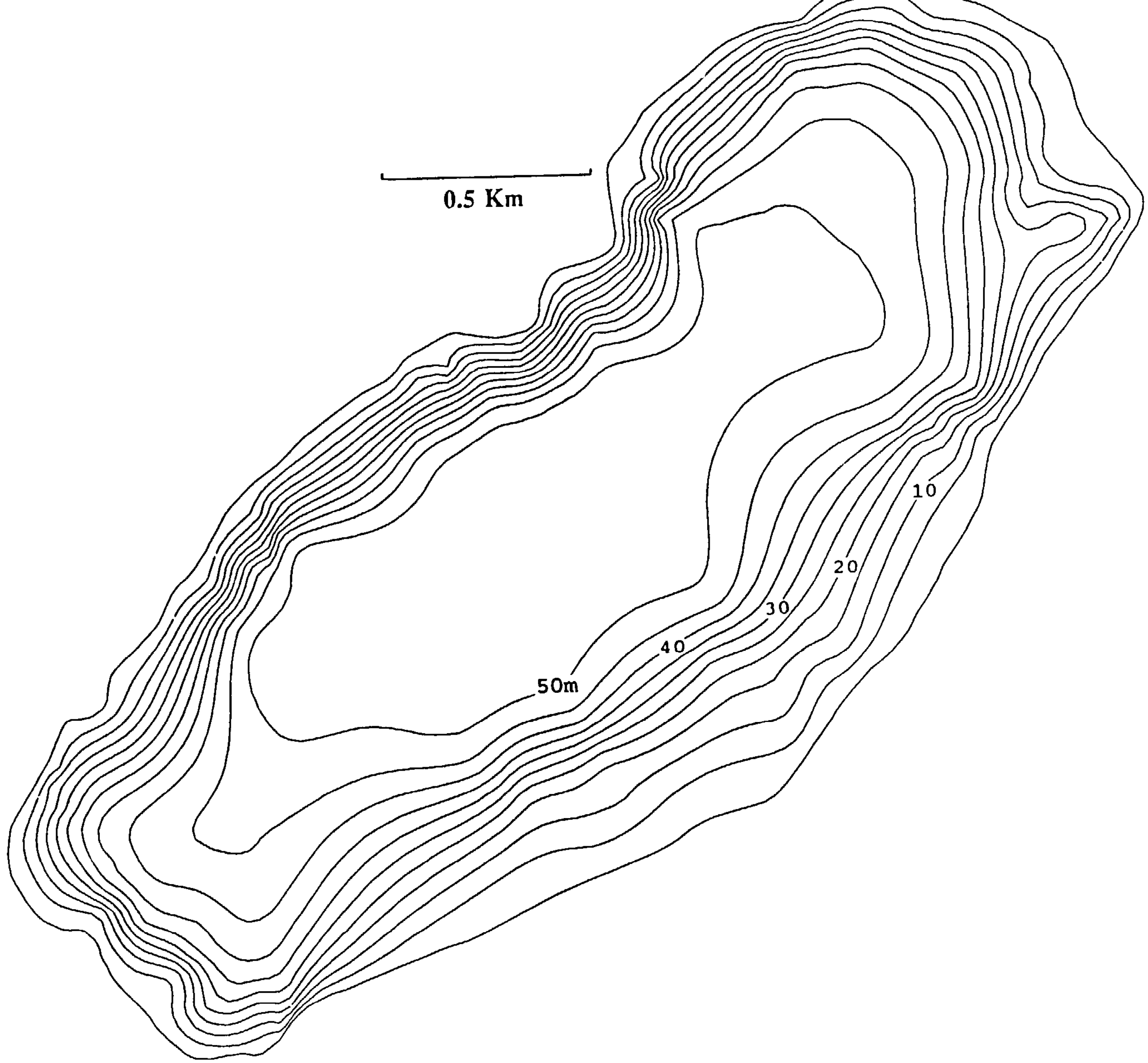
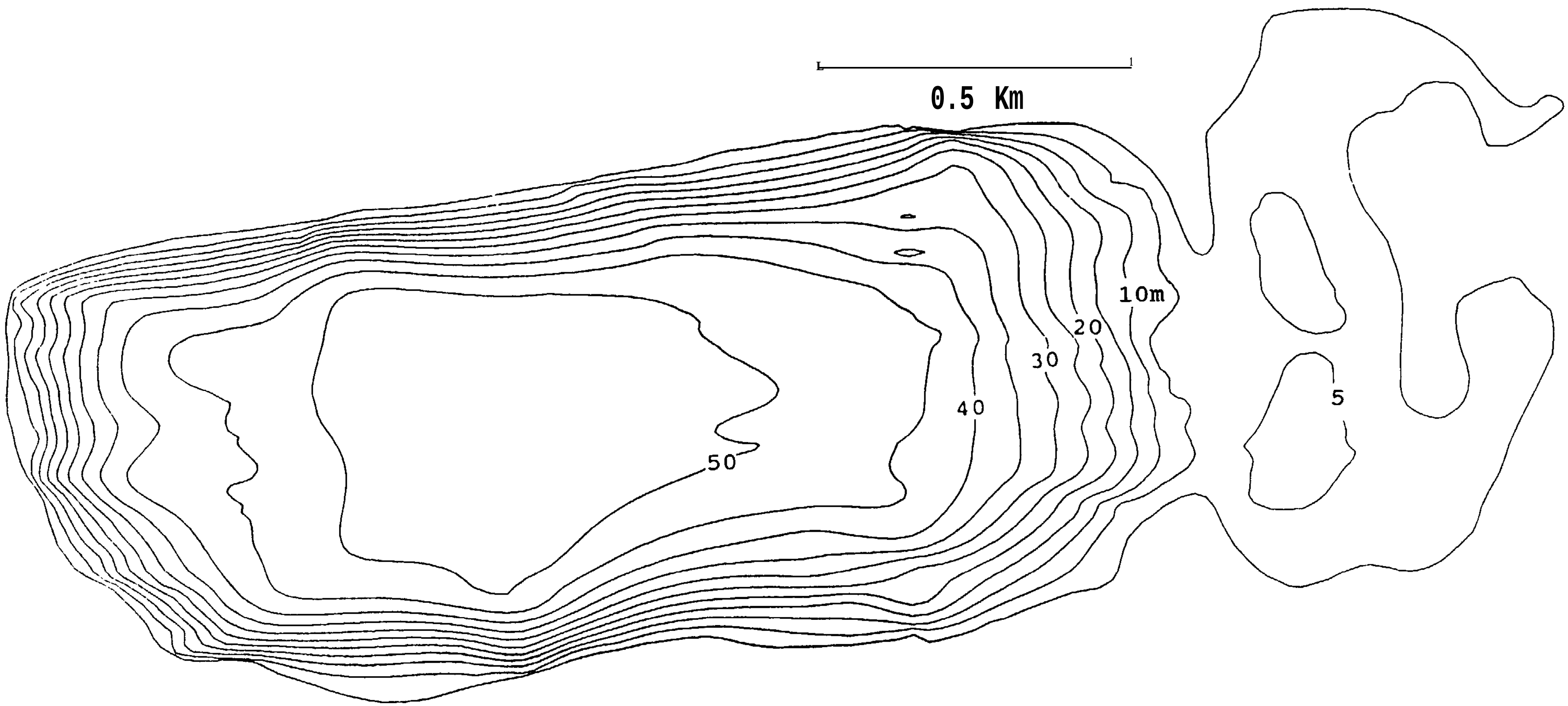
Appendix 1. Morphometric maps of the five study lakes. **Depth contours are shown in meters. True north is at the top of each map's heading.**

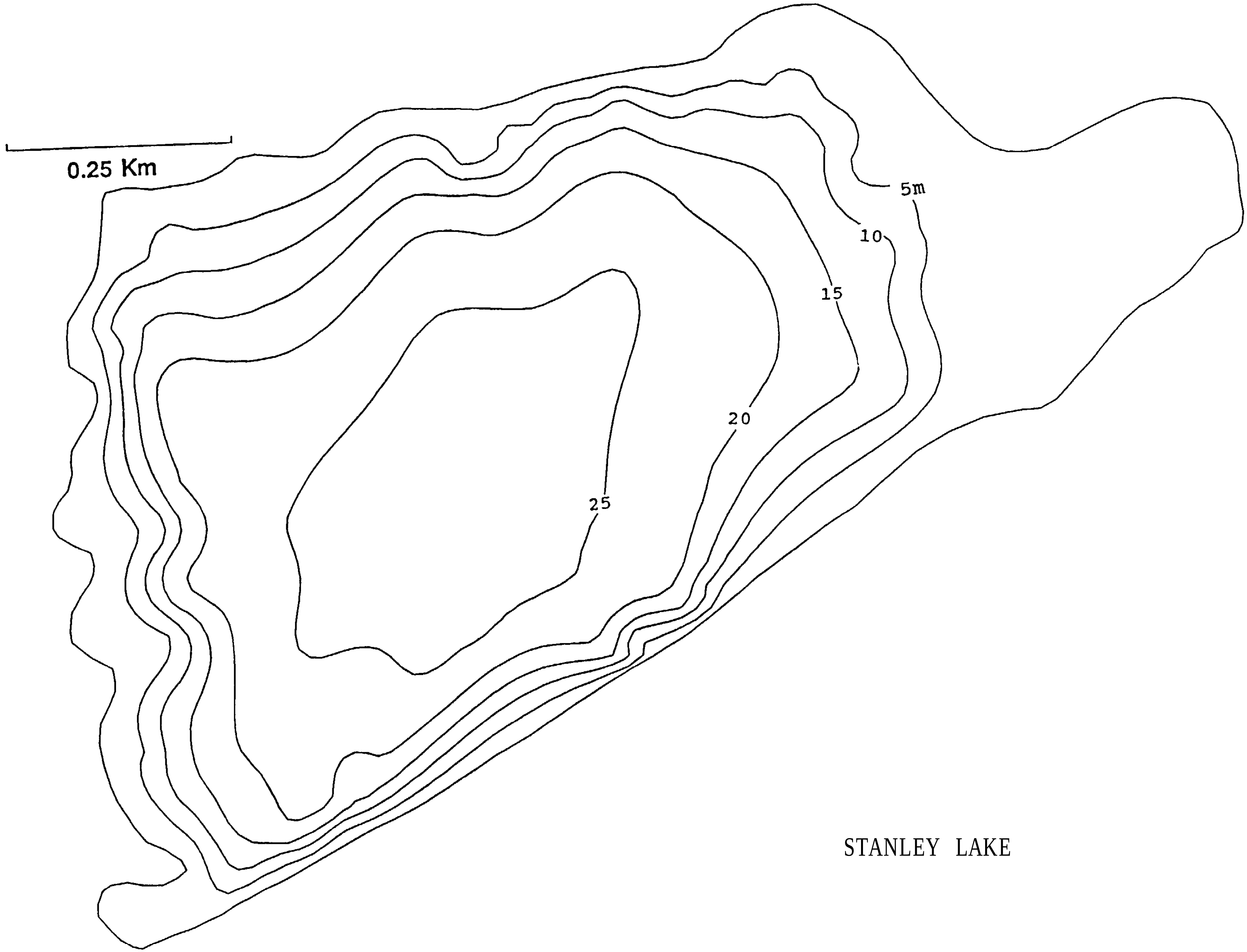

REDFISH LAKE
1.0 Km
10m
30
50
70
90

ALTURAS LAKE

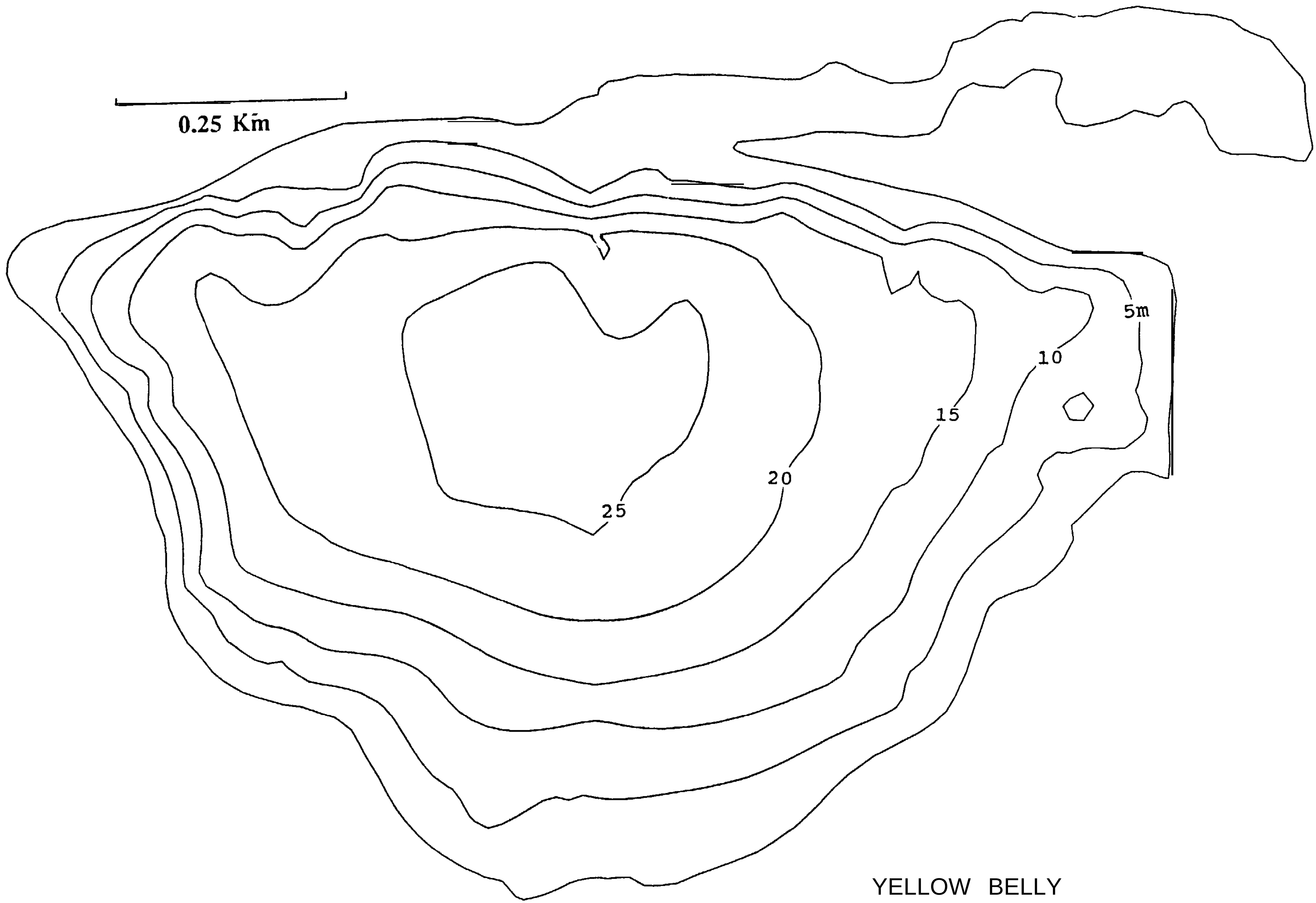


PETTIT LAKE

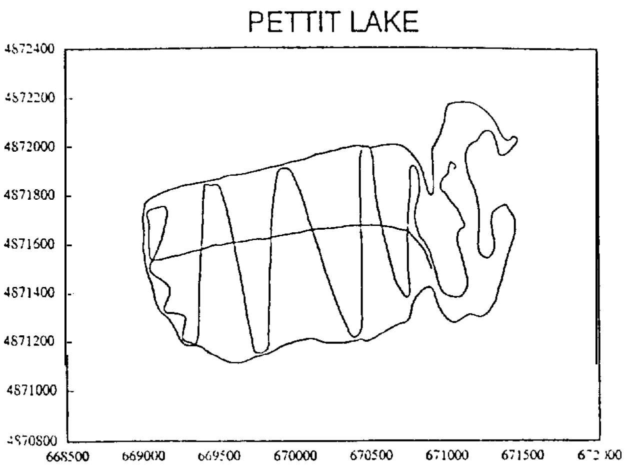


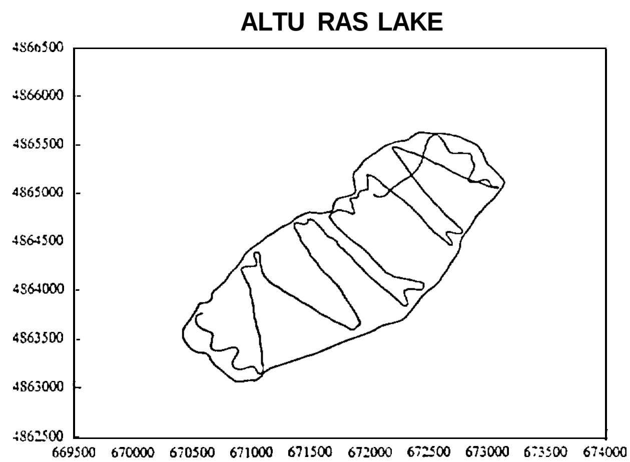


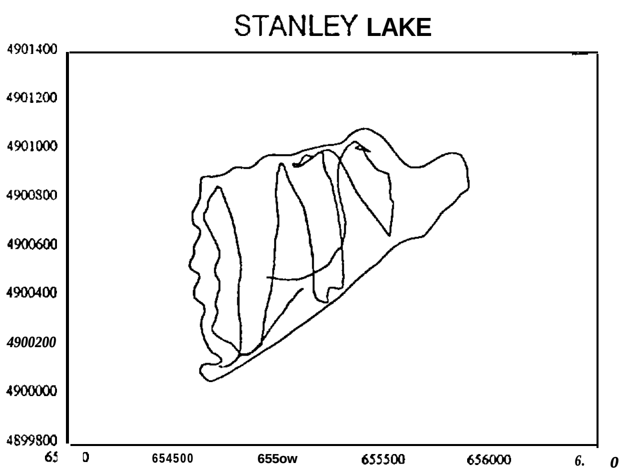
STANLEY LAKE

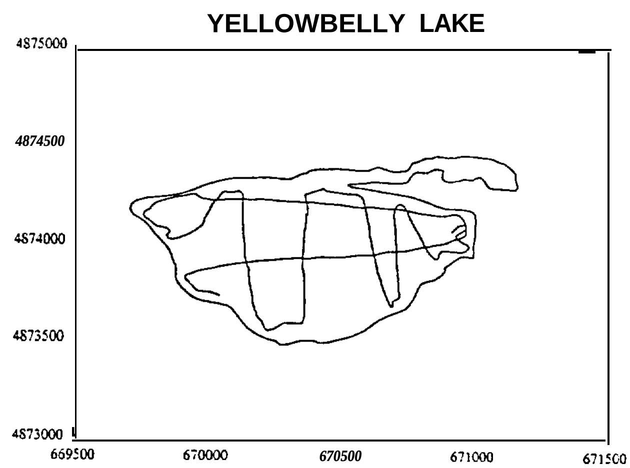

0.25 Km
5m
10
15
20
25
YELLOW BELLY

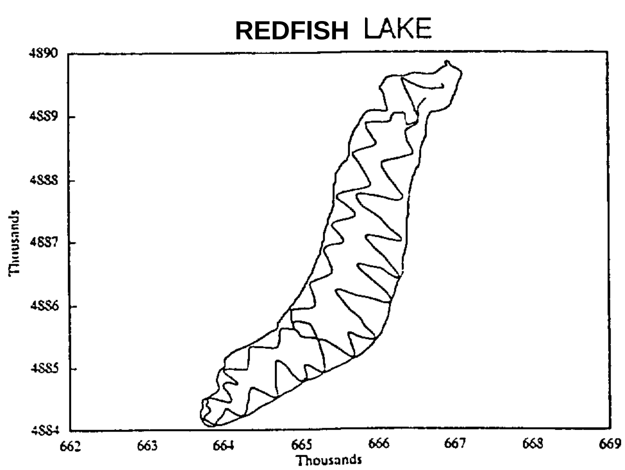
Appendix 2. Travel paths taken for recording depths in the Sawtooth Valley lakes.



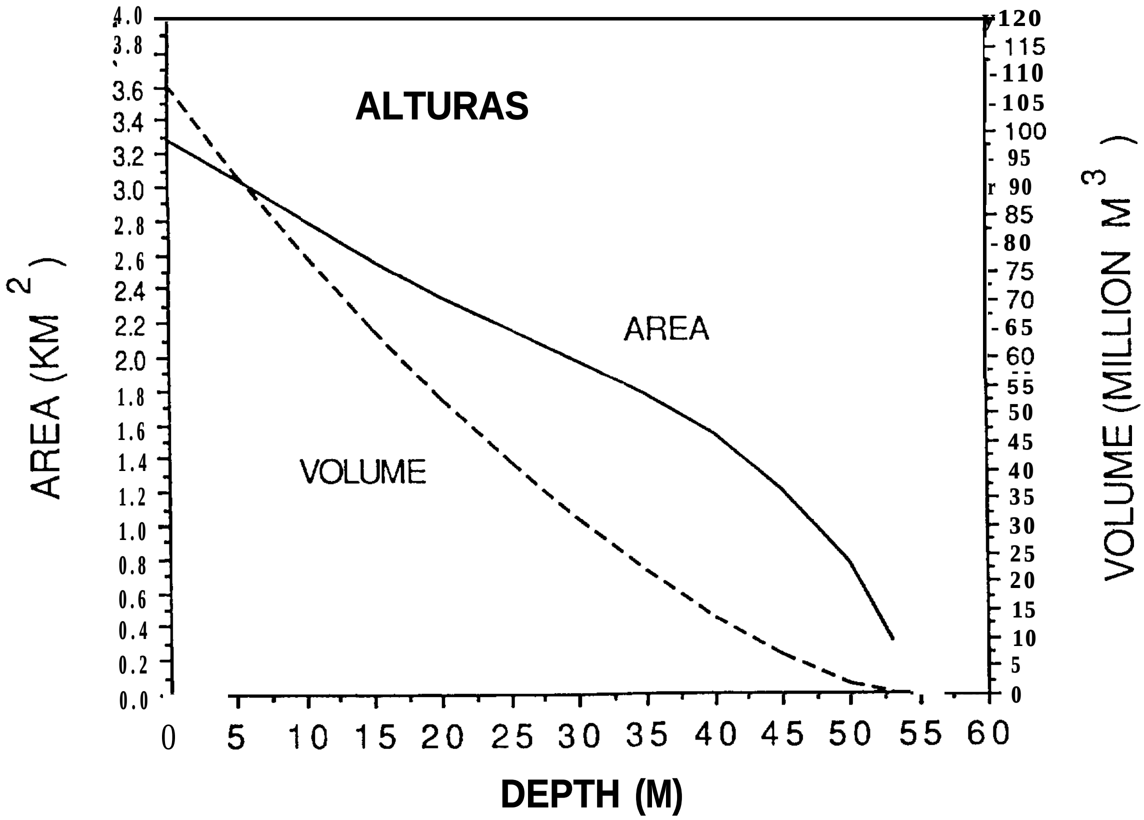


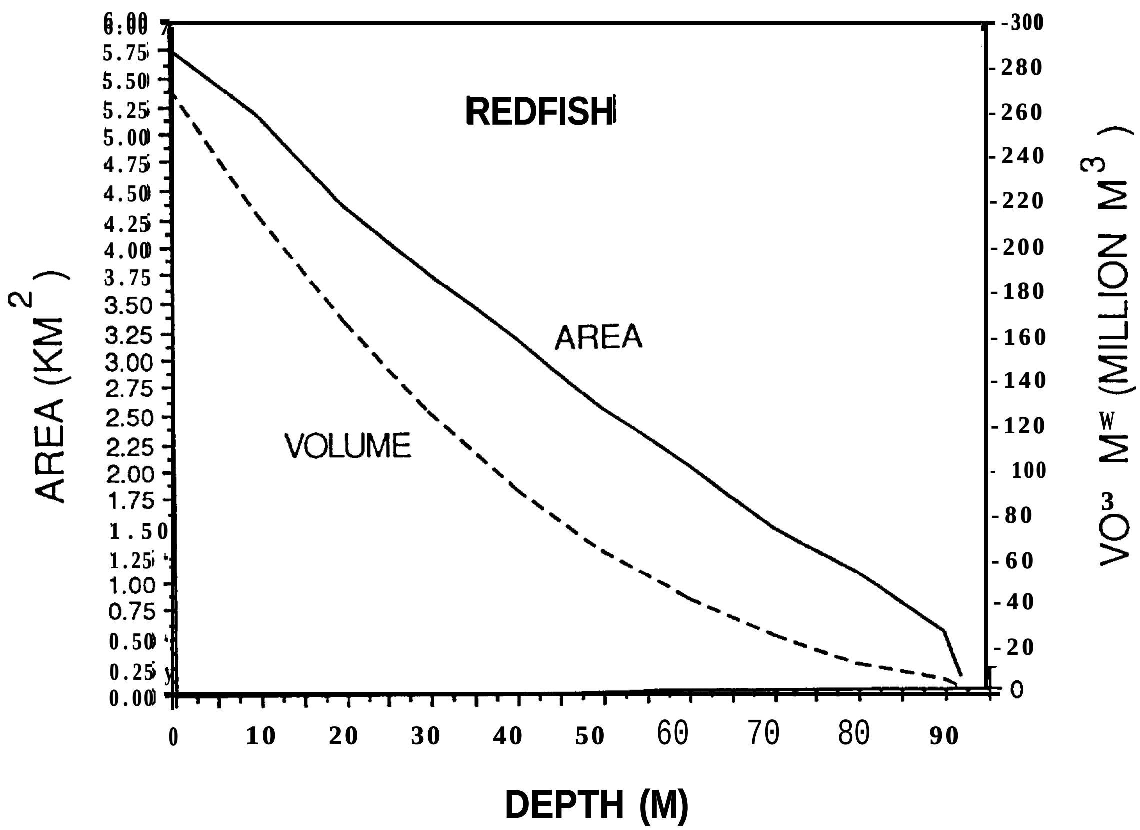


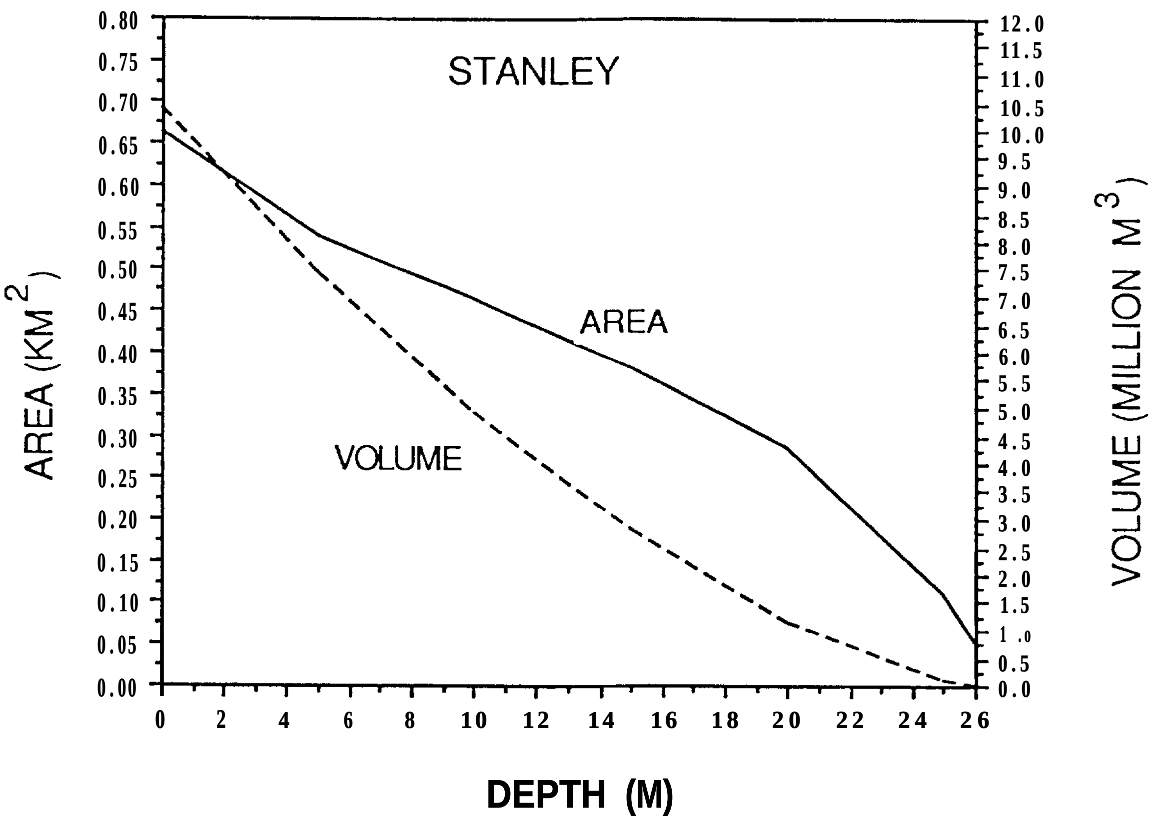


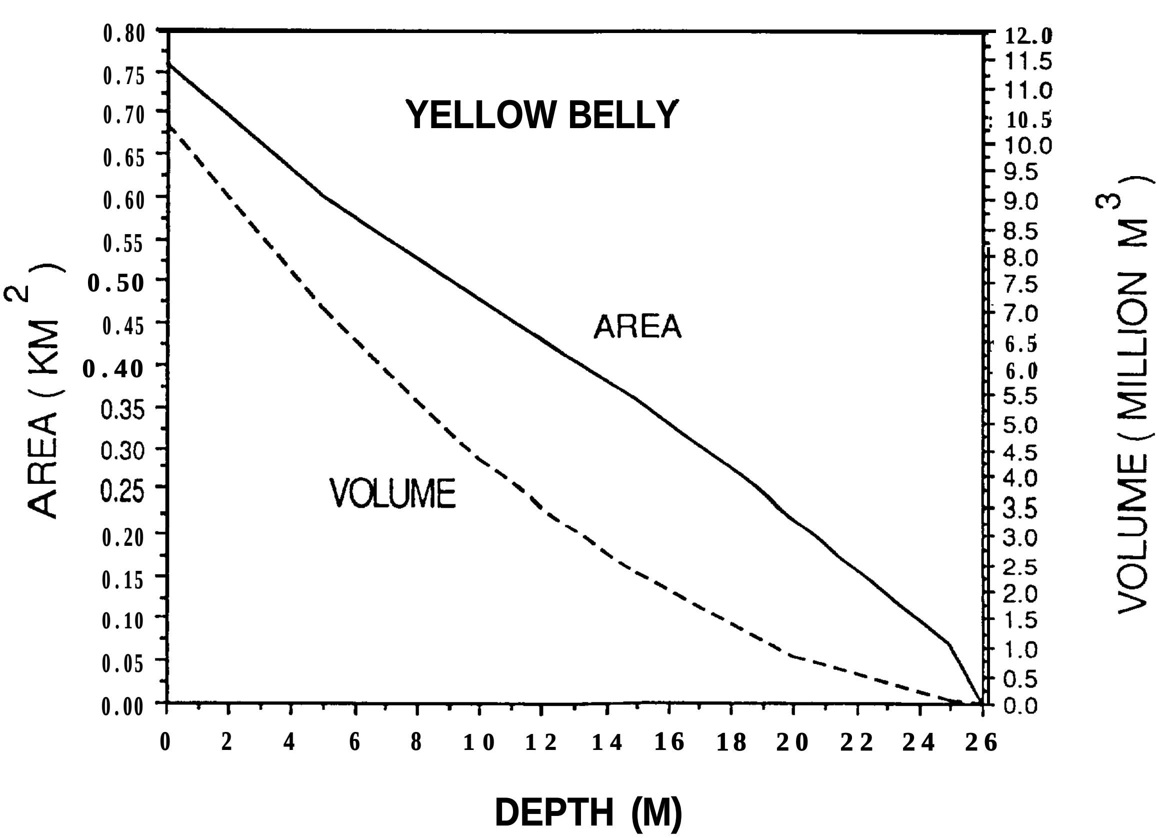


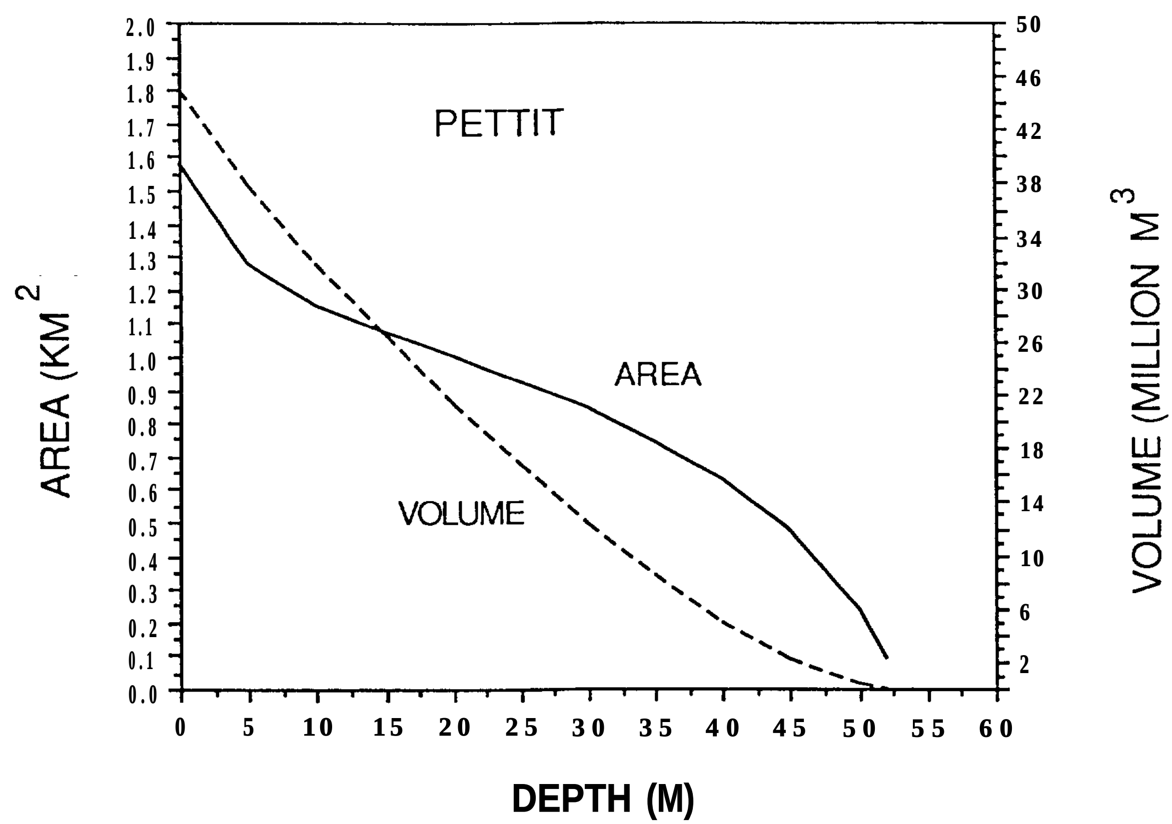
Appendix 3. Hypsographic and depth-volume curves for the five Sawtooth Valley lakes.


ALTURAS
AREA
VOLUME
AREA (KM 2)
VOLUME (MILLION M 3)
DEPTH (M)


REDFISH
AREA
VOLUME
AREA (KM 2)
DEPTH (M)

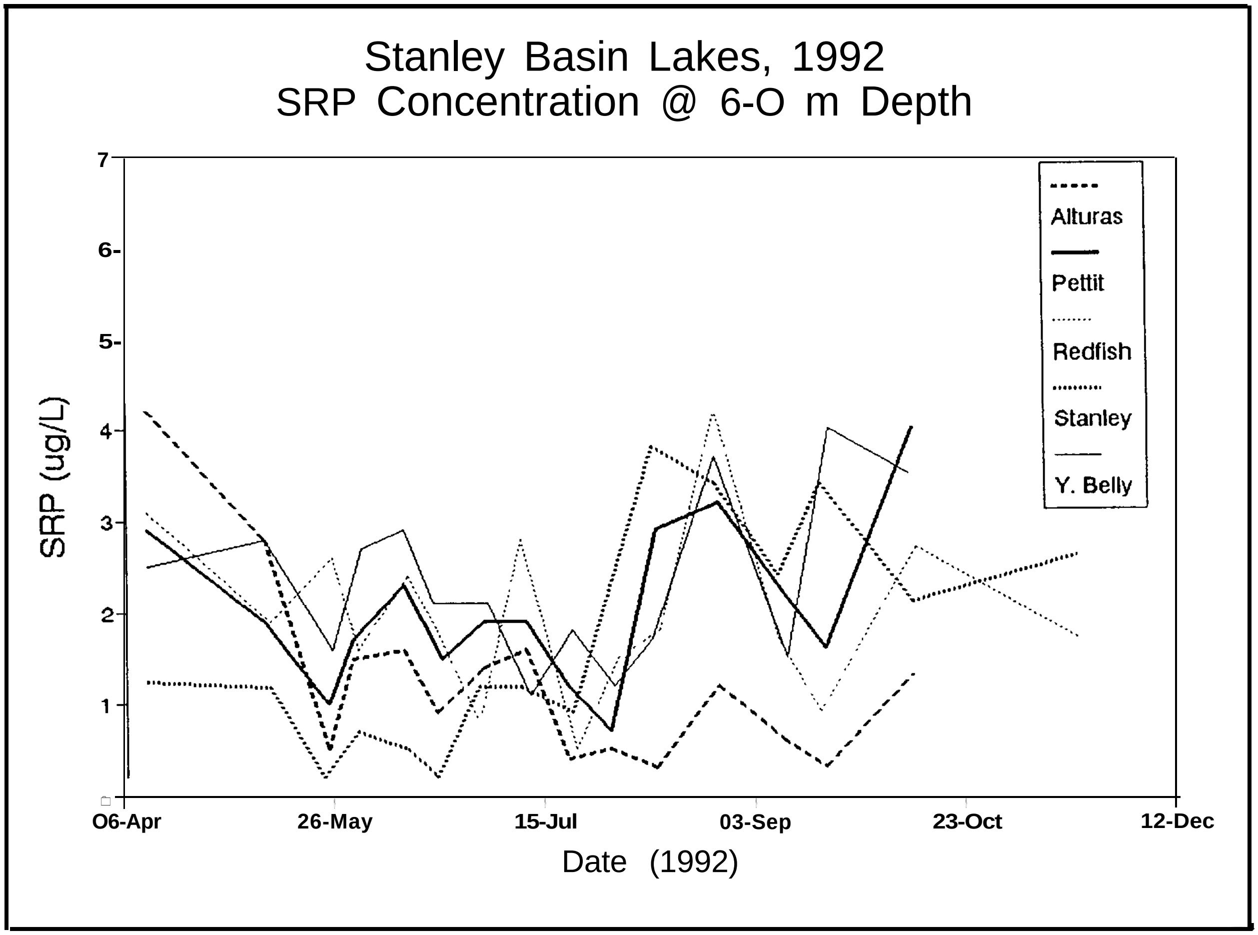

STANLEY
AREA
VOLUME
AREA (KM 2)
VOLUME (MILLION M 3)
DEPTH (M)
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
12.0
11.5
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0 2 4 6 8 10 12 14 16 18 20 22 24 26


YELLOW BELLY
AREA
VOLUME
AREA (KM 2)
VOLUME (MILLION M 3)
DEPTH (M)
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
12.0
11.5
11.0
10.5
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0 2 4 6 8 10 12 14 16 18 20 22 24 26

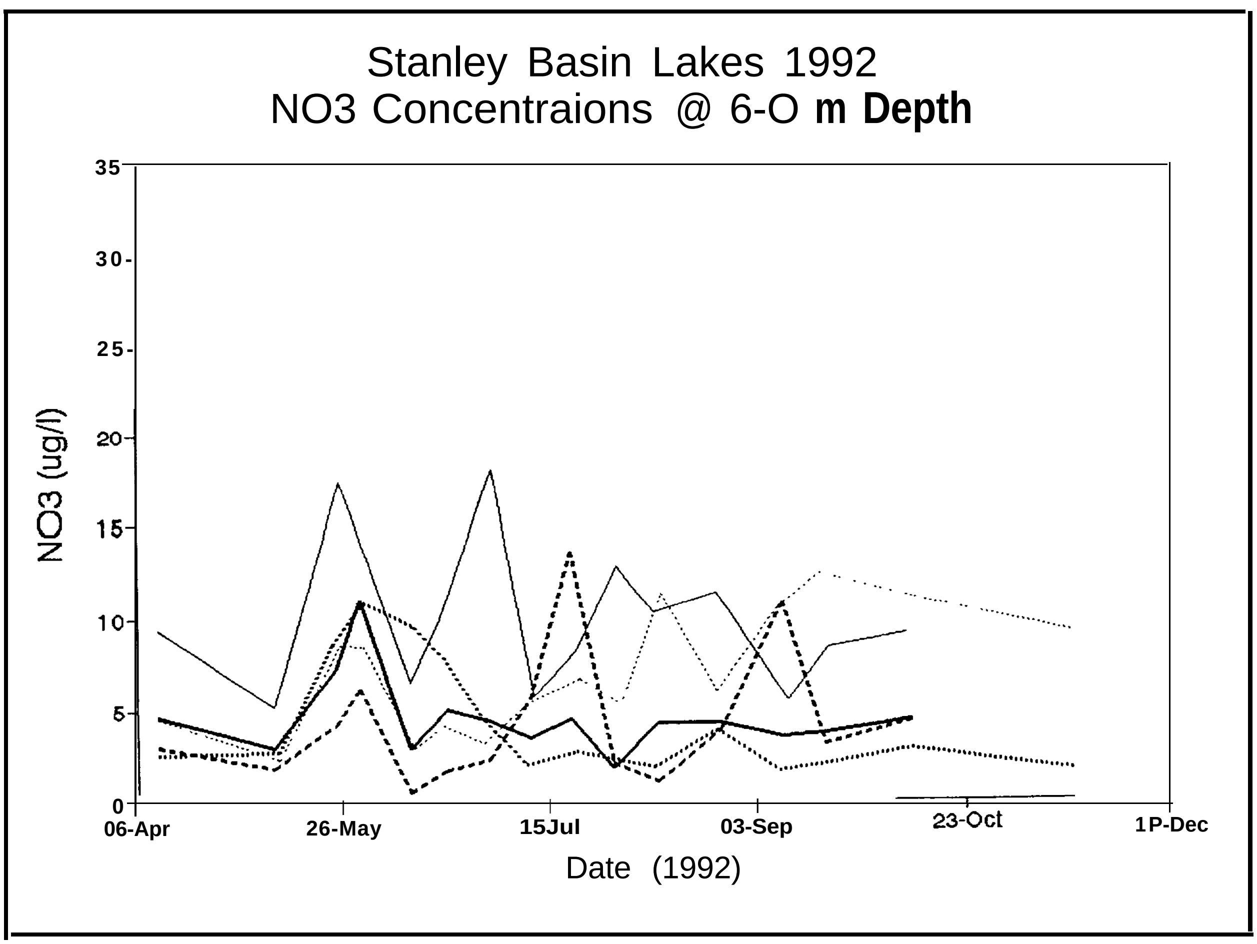

PETTIT
AREA
VOLUME
AREA (KM^2
VOLUME (MILLION M^3
DEPTH (M)
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
50
46
42
38
34
30
26
22
18
14
10
6
2
0 5 10 15 20 25 30 35 40 45 50 55 60

Appendix 4. Lake Nutrient Concentrations

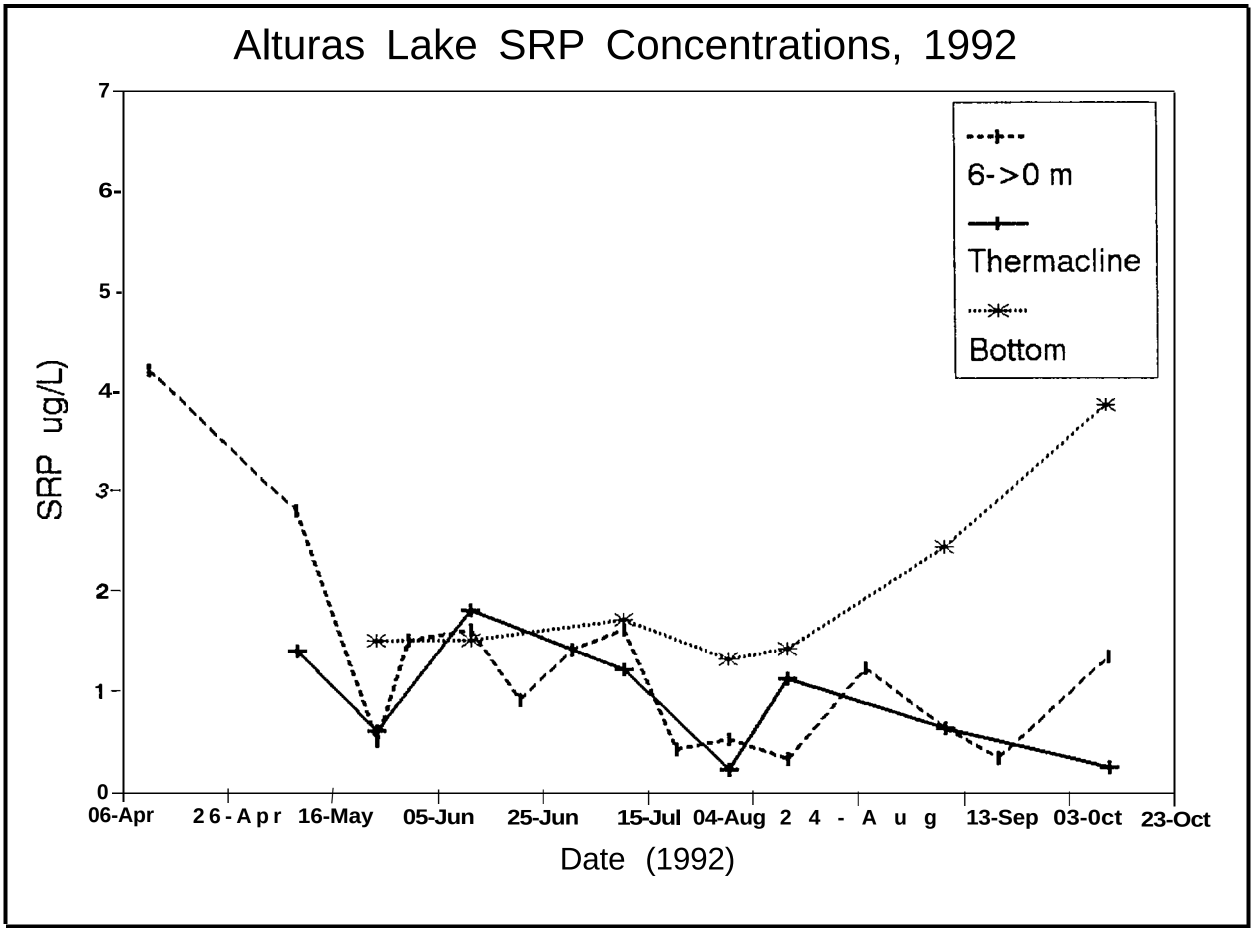
This appendix contains graphs of soluble reactive phosphorus (SRP) and nitrate-nitrogen (NO,-N) levels for the Sawtooth Valley Lakes. Samples were collected between April and November of 1992 as described in Budy et al. (Chapter 1). Analysis **was** performed using an autoanalyzer. Ongoing analysis will determine total phosphorus (TP), total nitrogen (TN), and ammonia-nitrogen (NH,-N) for the same sample dates for each lake.



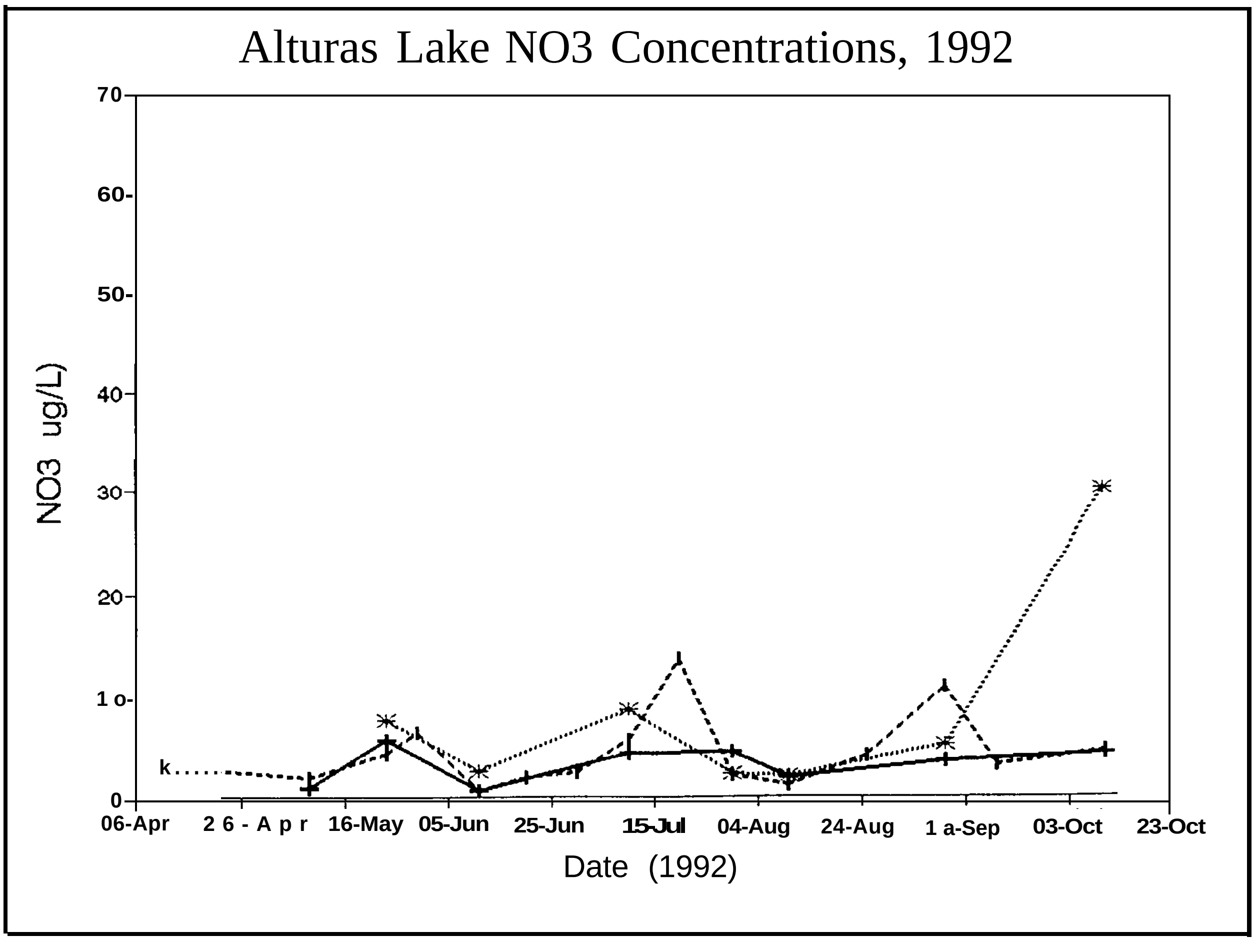
nutrient\srp\srpgraph.wq1 graph: 5 lakes



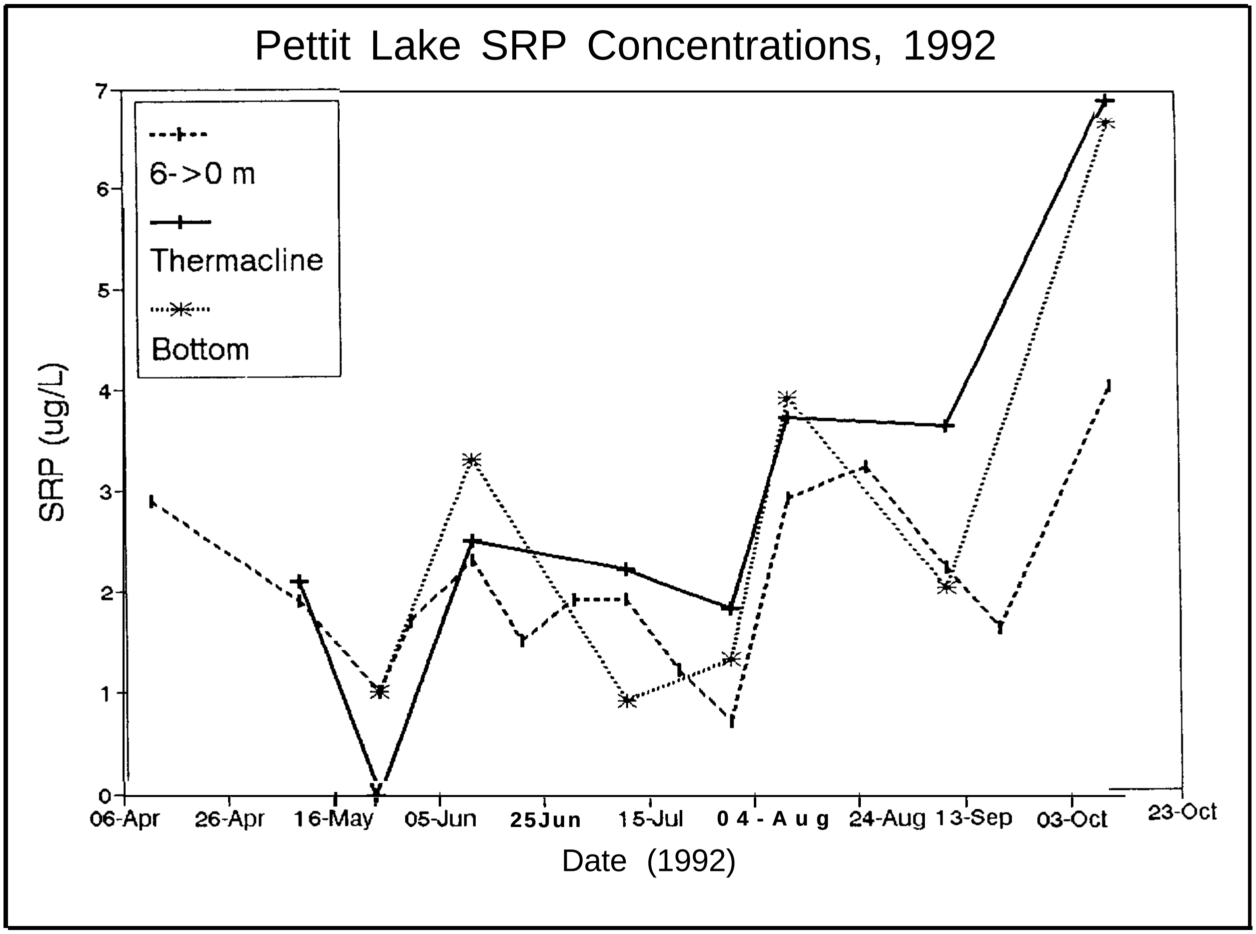
nutrient\no3\no3graph.wpl graph: 5 lakes



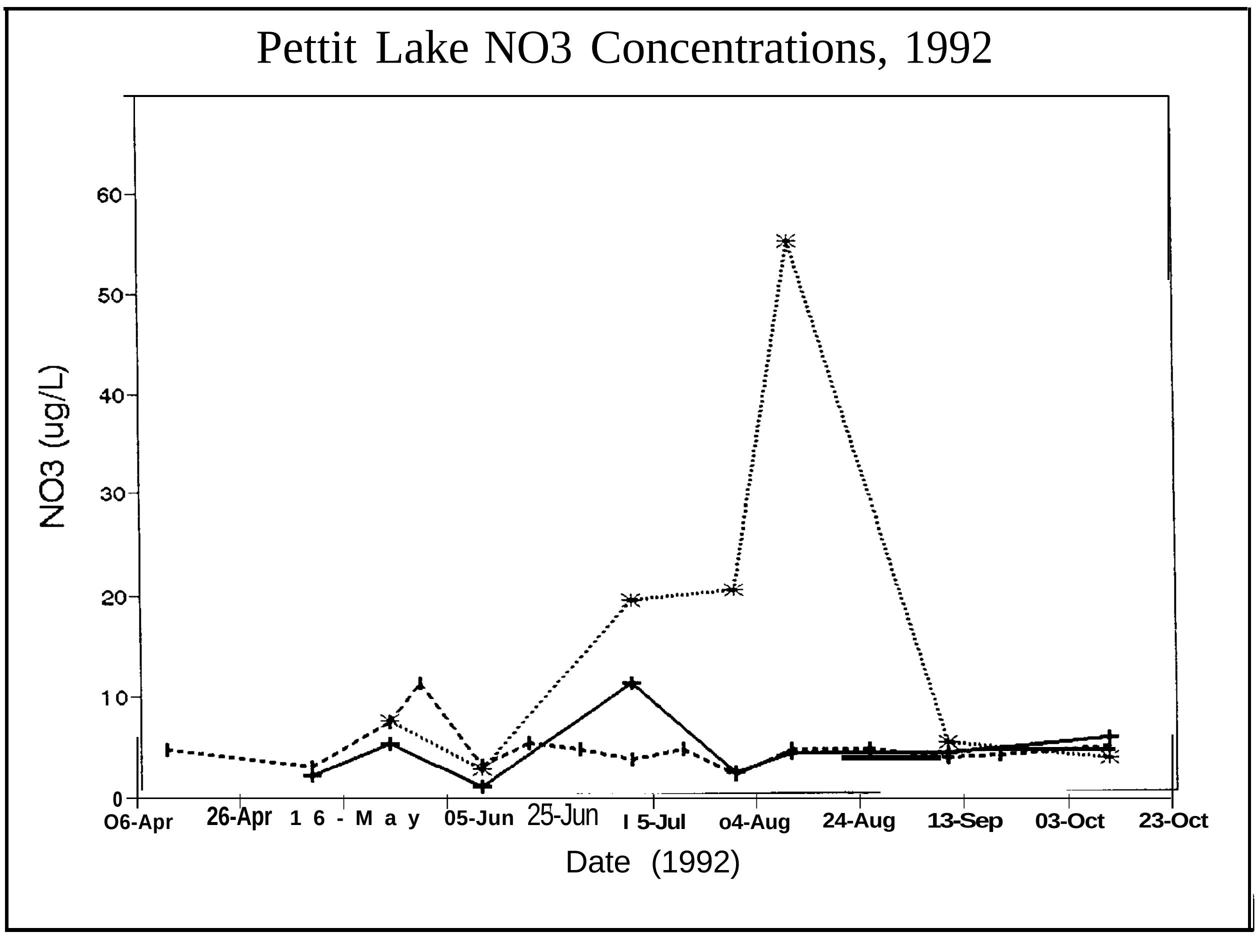
nutrient\srp\srpgraph.wql graph: alturas



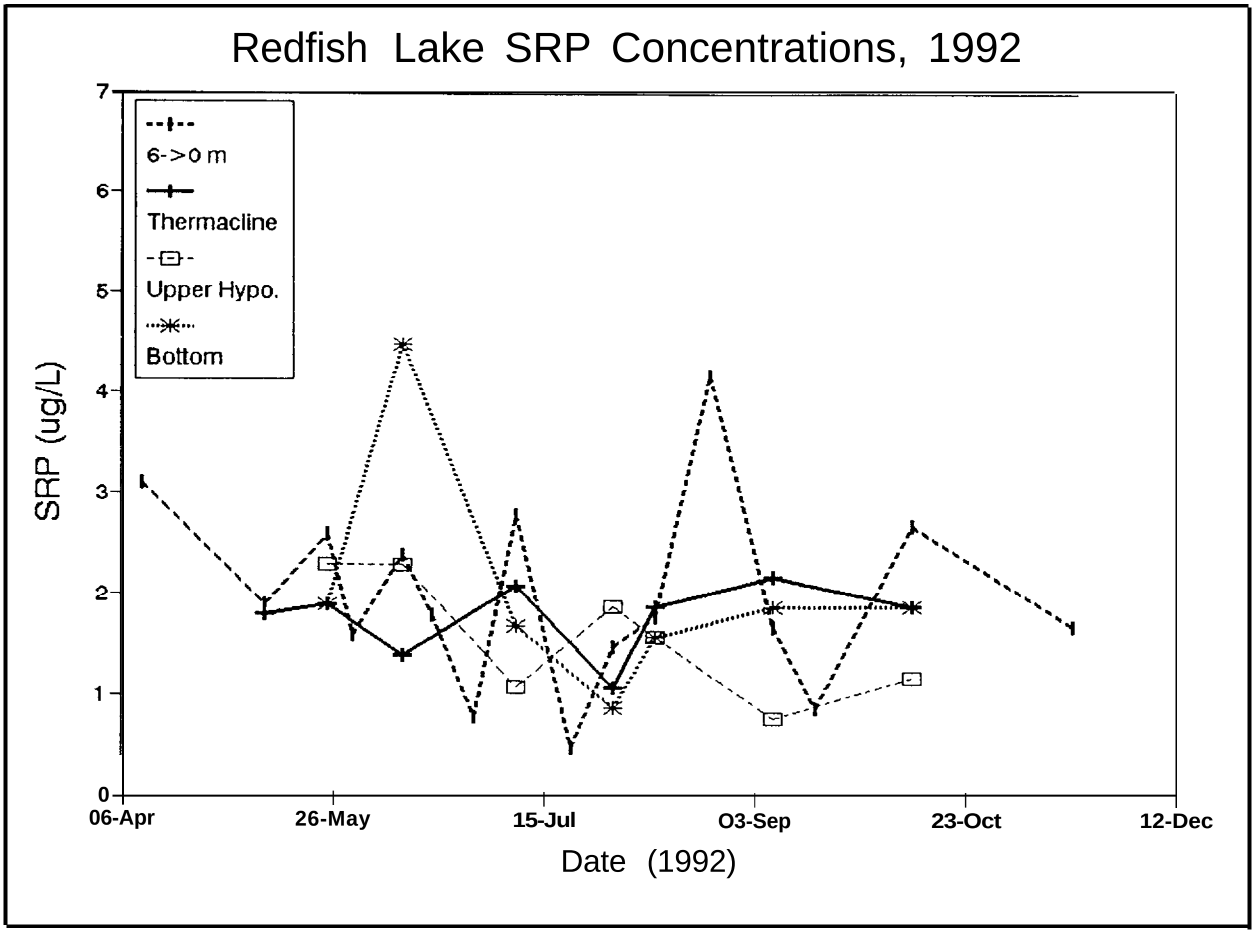
nutrient\no3\no3graf2.wq1 graph: alturas



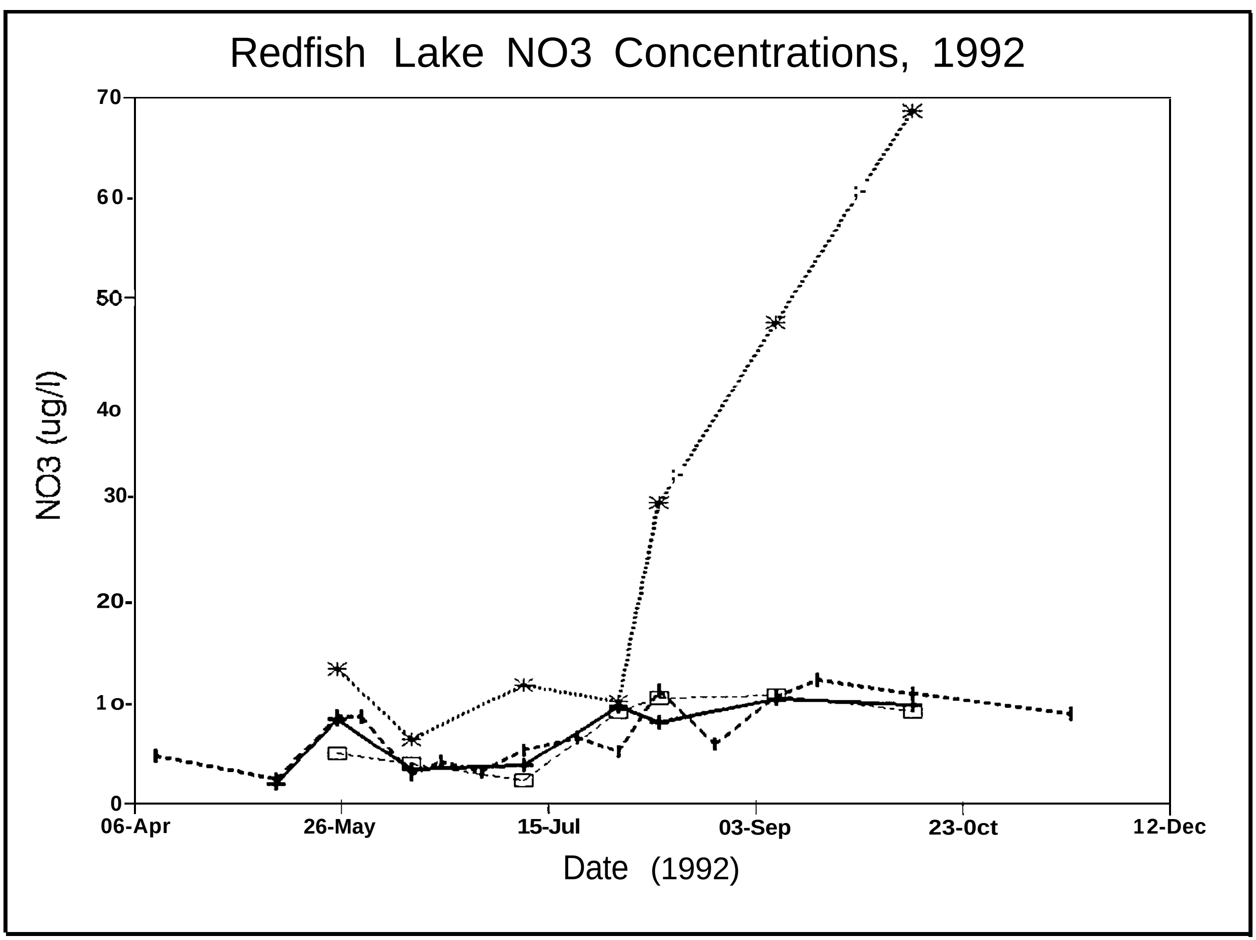
nutrient\srp\srpgraph.wq1 graph: pettit



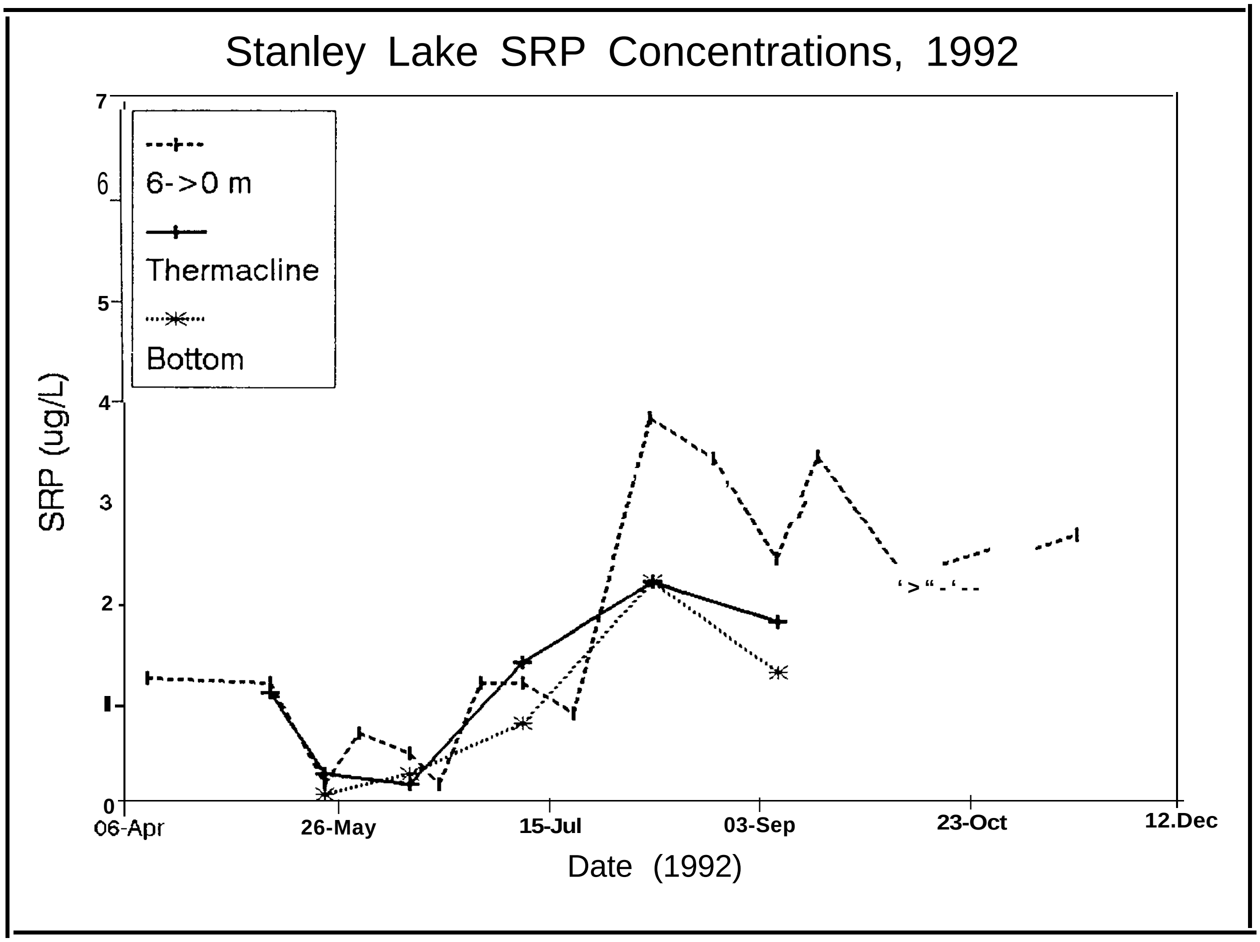
nutrient\no3\no3graf2.wq1 graph: pettit



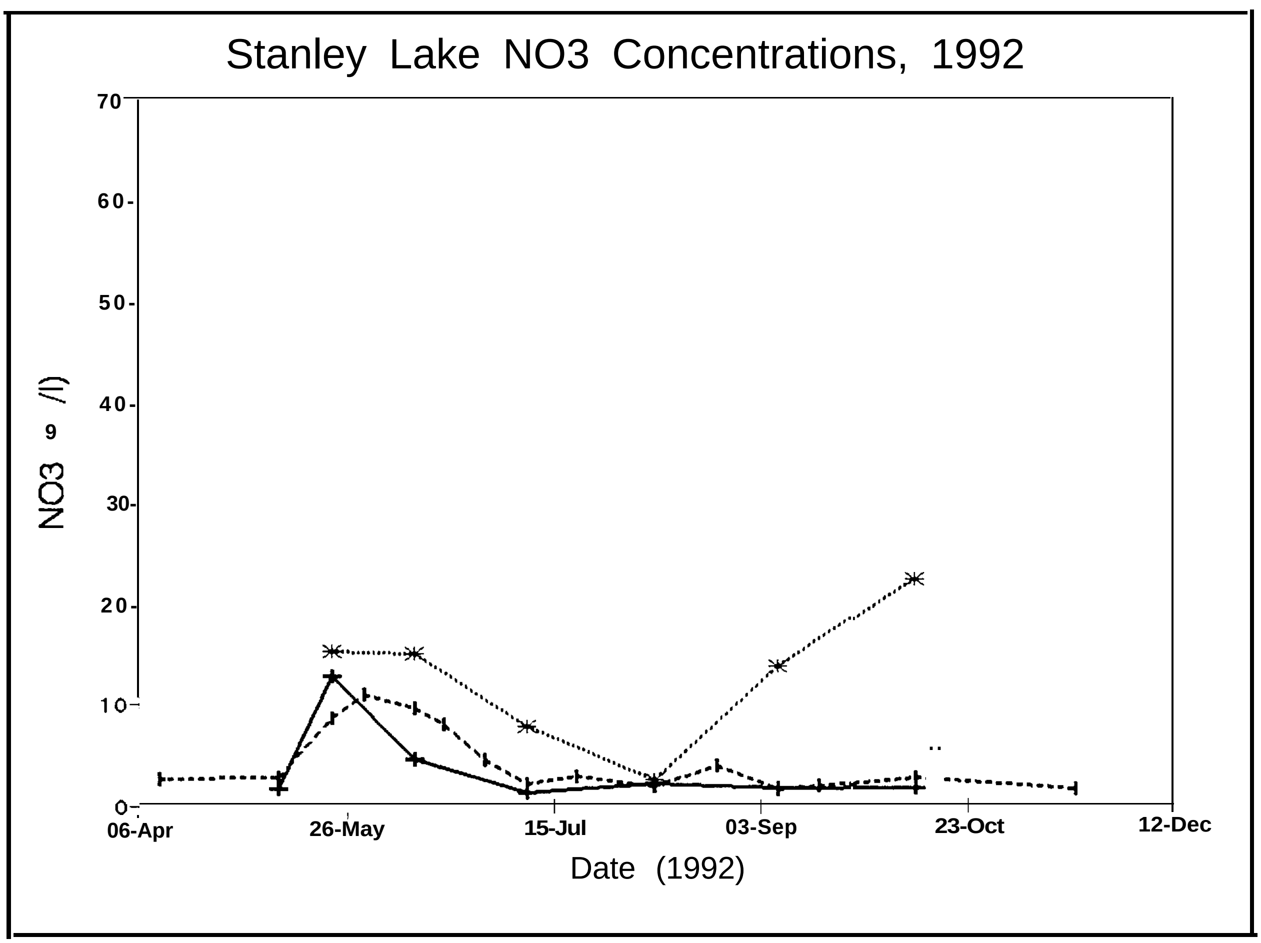
nutrient\srp\erpgraph.wql graph: redfish

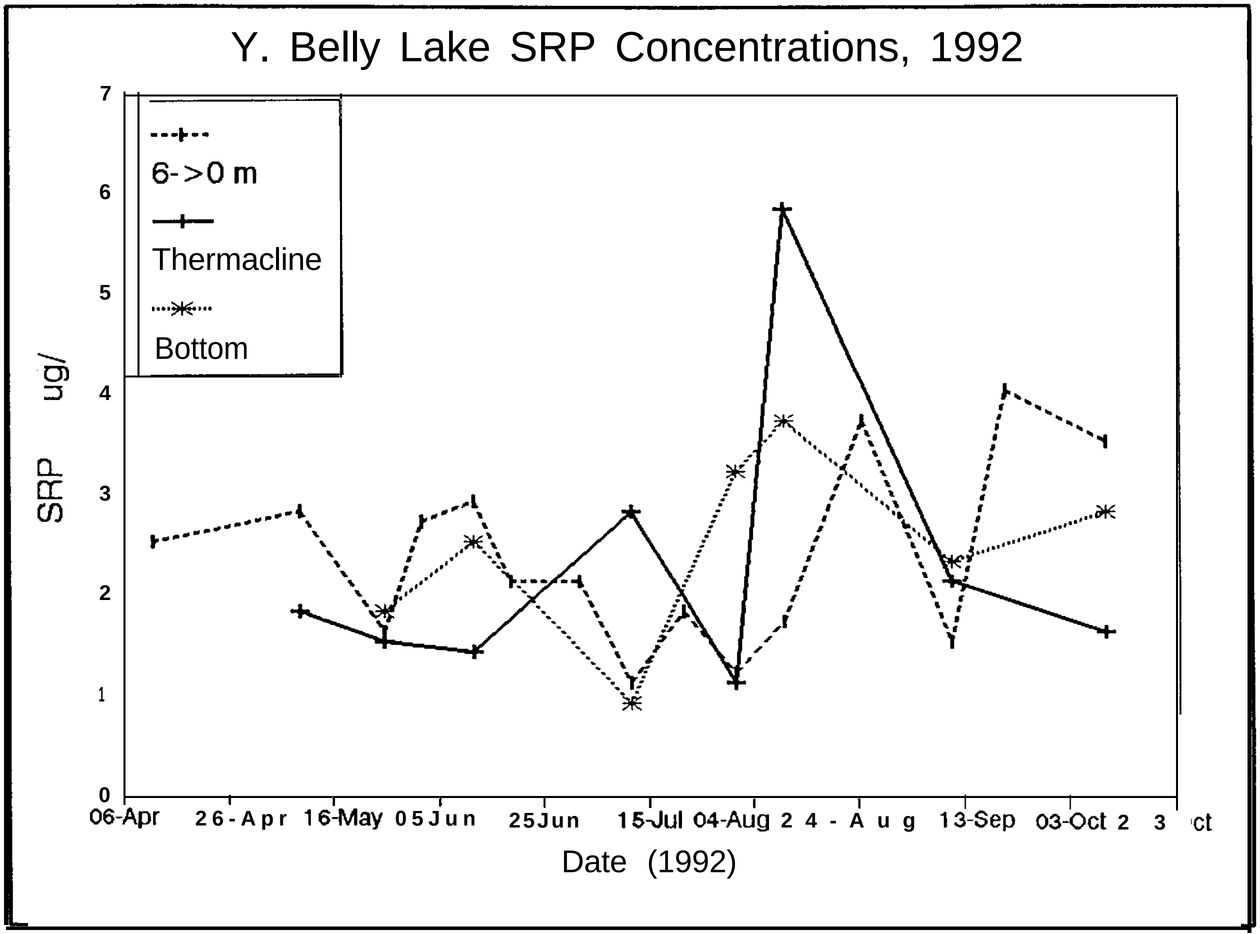


nutrient\no3\no3graph.wql graph: redfish

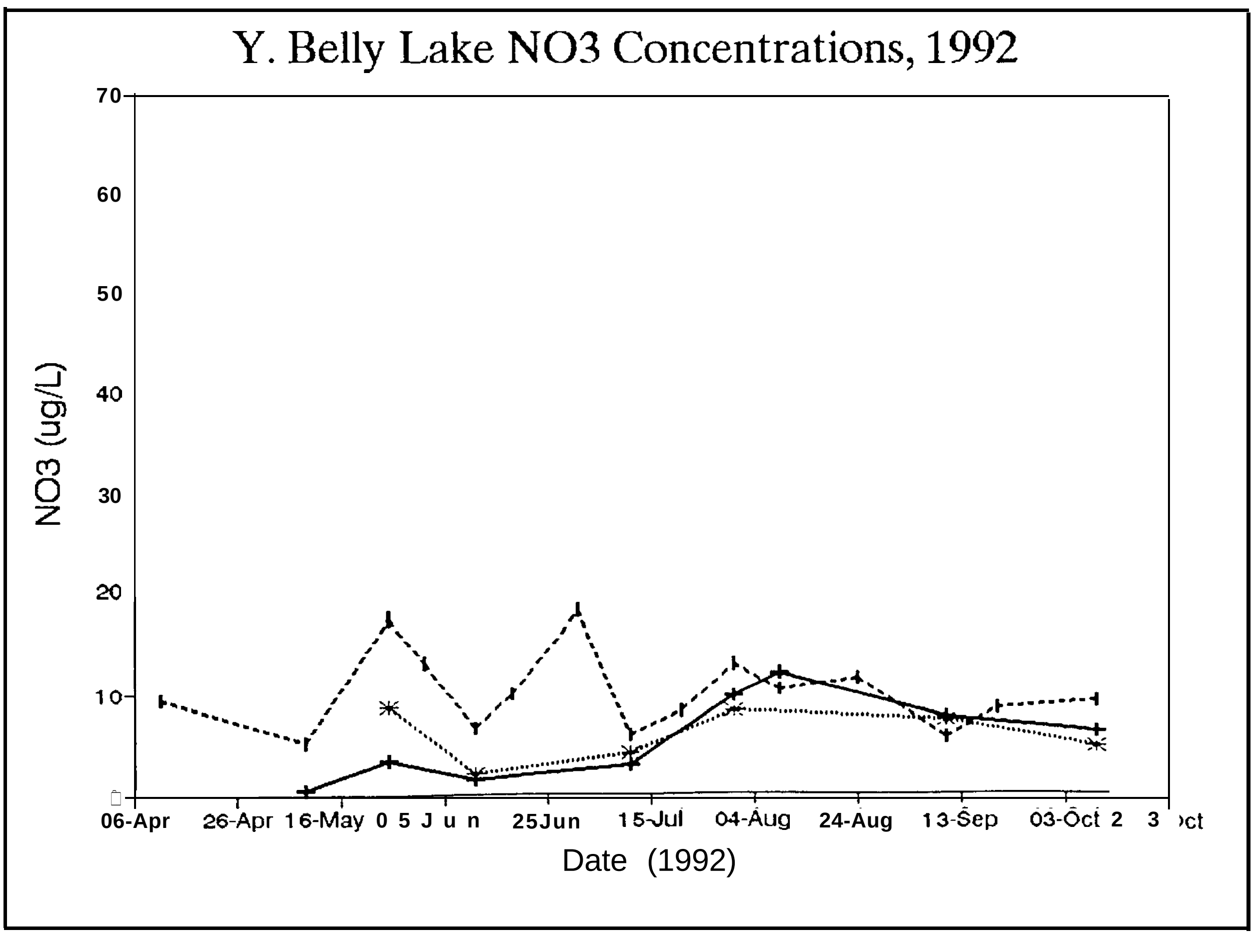


nutrient\srp\srpgraph.wql graph: Stanley





nutrient\srp\srpgraph.wq1 graph: ybelly



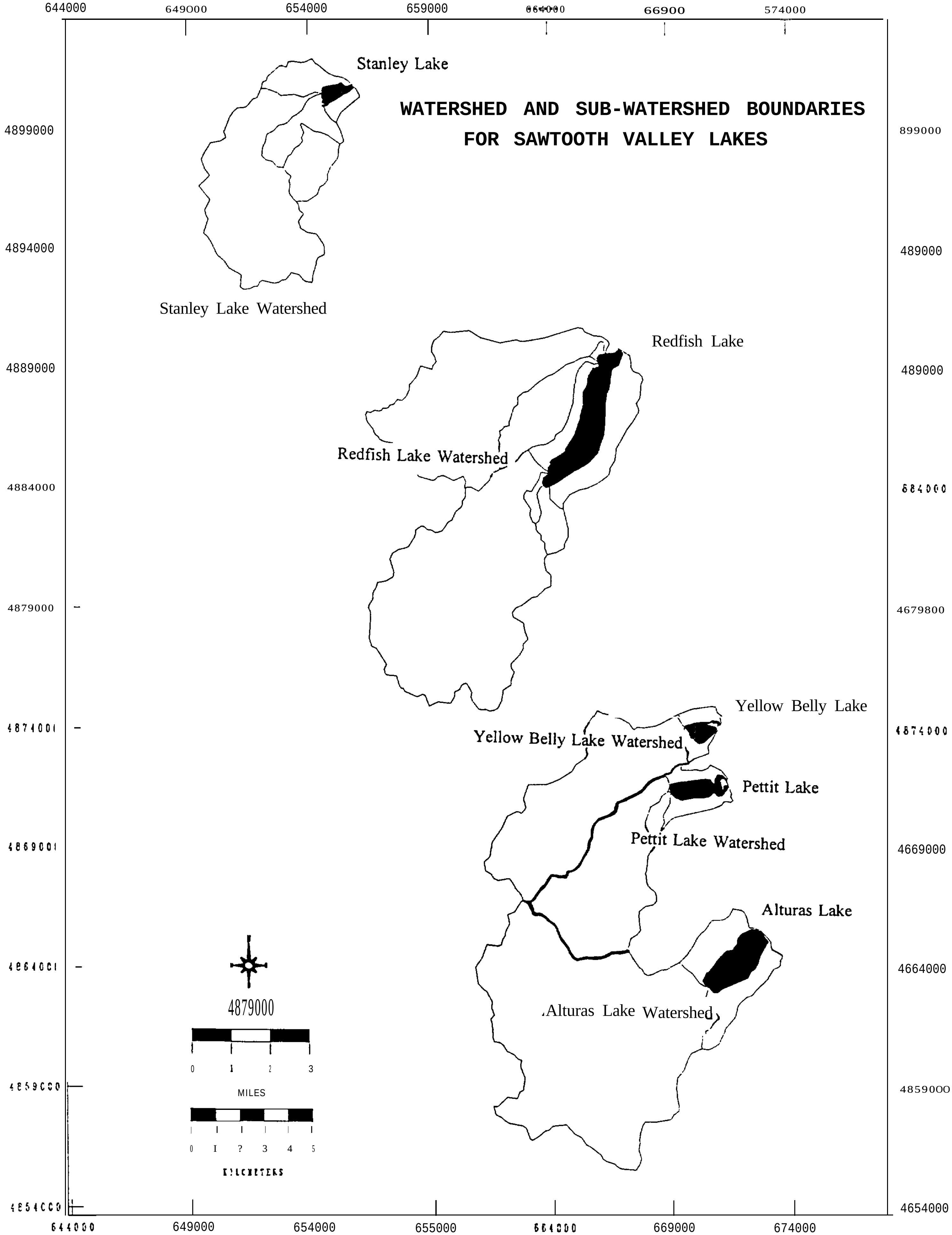
nutrient\no3\no3graf2.wq1 graph: ybelly

Appendix 5. Hydrographs and Watershed Map

Discharge was measured for the twelve inlets and outlets of the Stanley Basin Lakes in 1992 11-13 times between May and October. A Marsh McBurney Flo-Mate 2000 electromagnetic flow meter was used to measure stream velocities. In the spring, stage gauges were installed on each stream. Stage height was recorded whenever discharge was measured in order to establish a stage-discharge relationship for each stream. This allowed us to determine discharge on several occasions during the sampling season without measuring stream velocities or cross-sectional dimensions. Discharges from January through early May and from mid-October through December were derived using correlations of our stream flows and United States Geological Survey stream flow data. Thus, the hydrographs were created using an array of measuring techniques and available data.

Estimated annual flow figures are listed on each hydrograph. Inflow and outflow figures for each lake rarely add up. This is because contributions to a lake's water budget come from sources besides inflow and outflow streams (for example, evaporation, groundwater, precipitation, and seepage). In addition, each lake's watershed has areas which drain into the lake through surface and subsurface runoff. For 1993, the following actions are being considered in order to improve our water budget, and thus nutrient budget measurements:

- measurement of nutrient content and snow water equivalent from snow core samples taken from above the ice of each lake in late March.
- measurement of water quality from precipitation samples collected at Redfish Lake (to be coupled with precipitation quantity measurements recorded by the USFS at the Stanley Ranger Station).
- estimation of nutrient input from contributing watershed areas not drained by streams.


WATERSHED AND SUB-WATERSHED BOUNDARIES
FOR SAWTOOTH VALLEY LAKES
Stanley Lake
Stanley Lake Watershed
Redfish Lake
Redfish Lake Watershed
Yellow Belly Lake
Yellow Belly Lake Watershed
Pettit Lake
Pettit Lake Watershed
Alturas Lake
Alturas Lake Watershed
644000
649000
654000
659000
674000
4899000
4894000
4889000
4884000
4879000
4669000
4664000
4859000
4654000
655000
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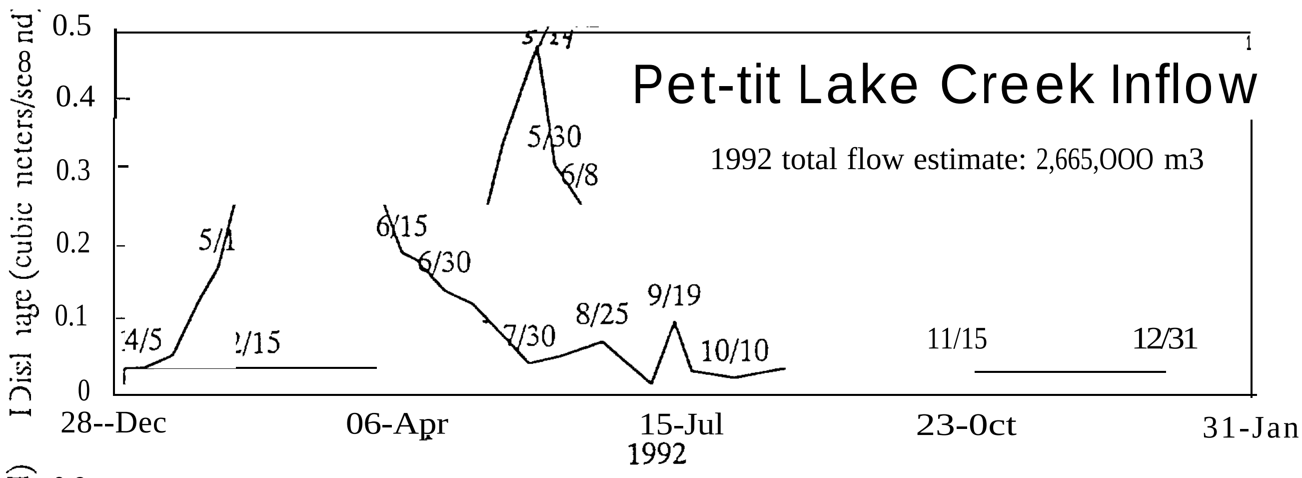
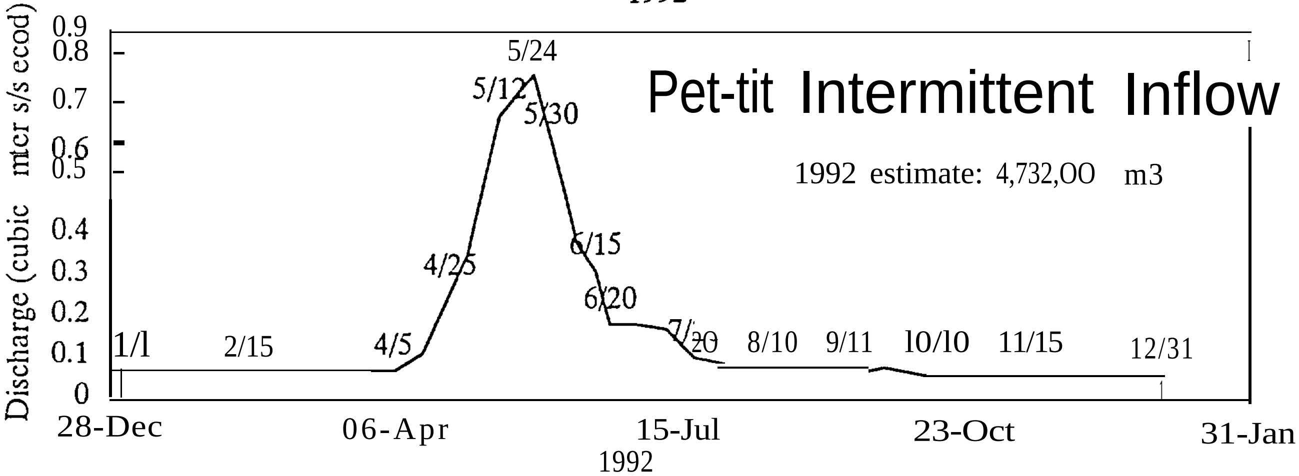
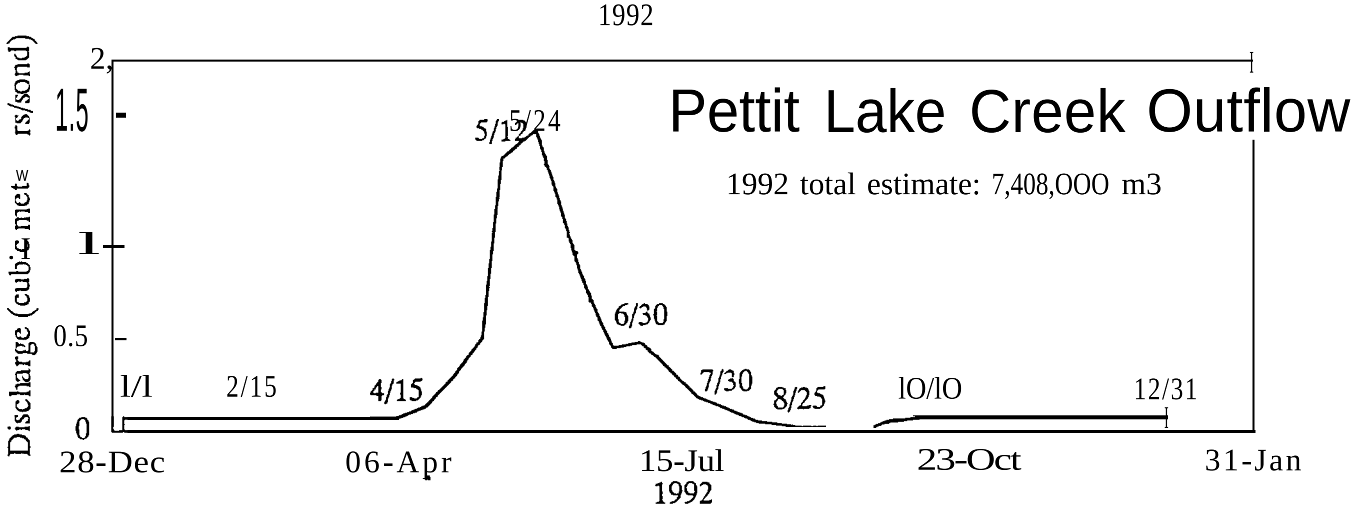
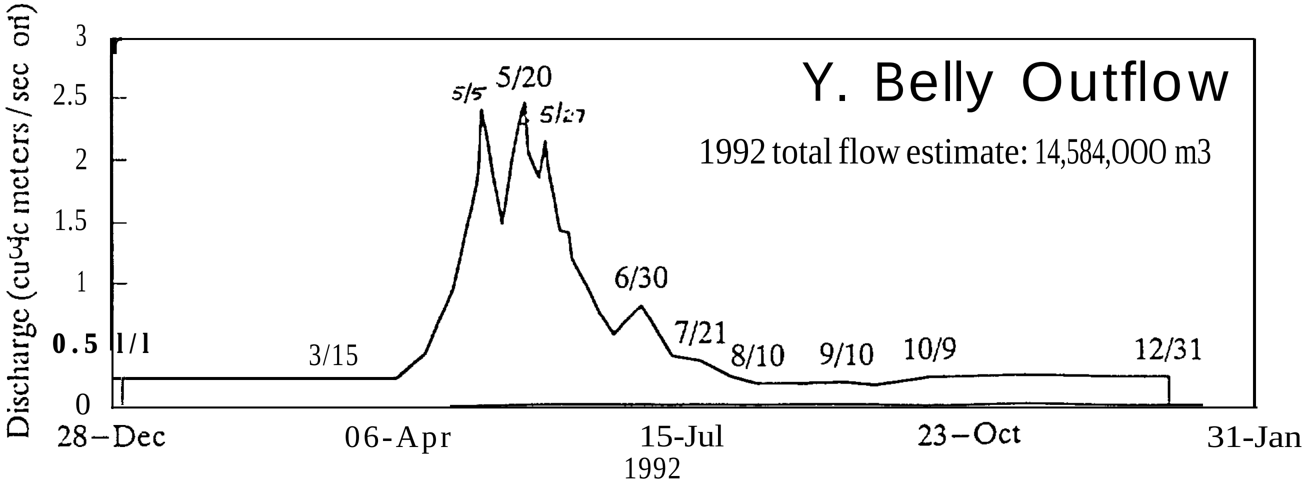
0
1
2
3
MILES
0
1
3
4
5

Hydrographs

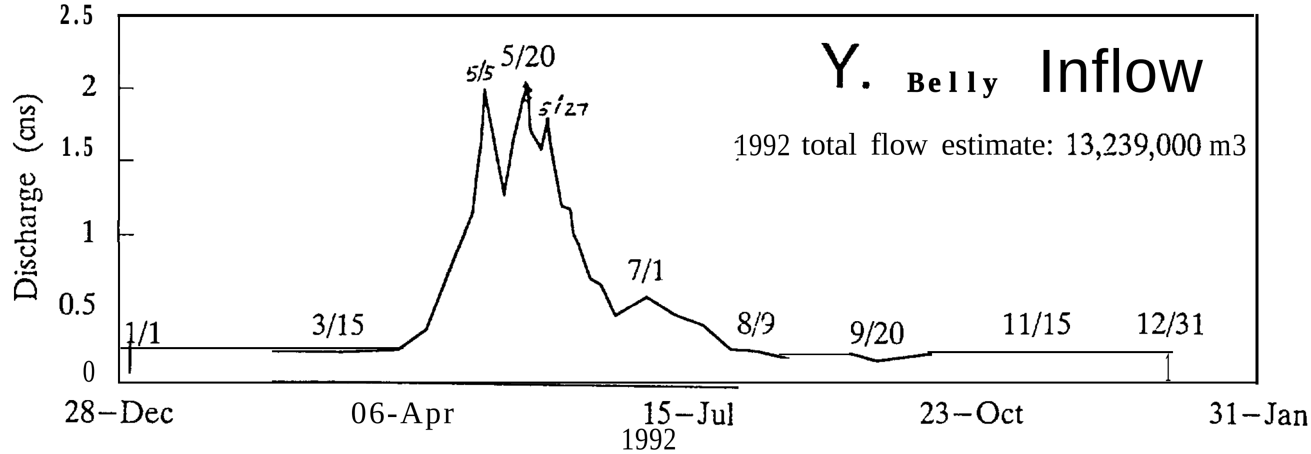


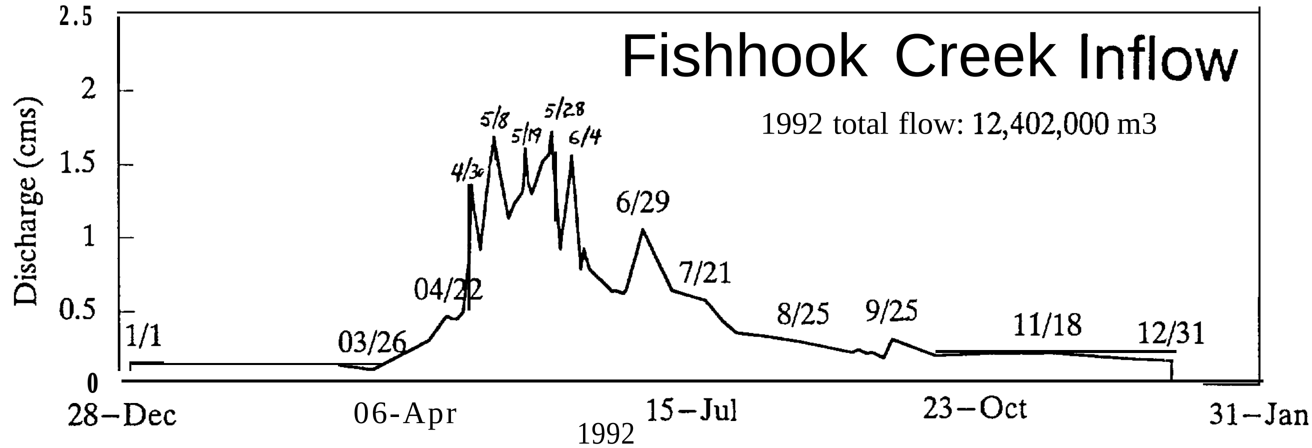


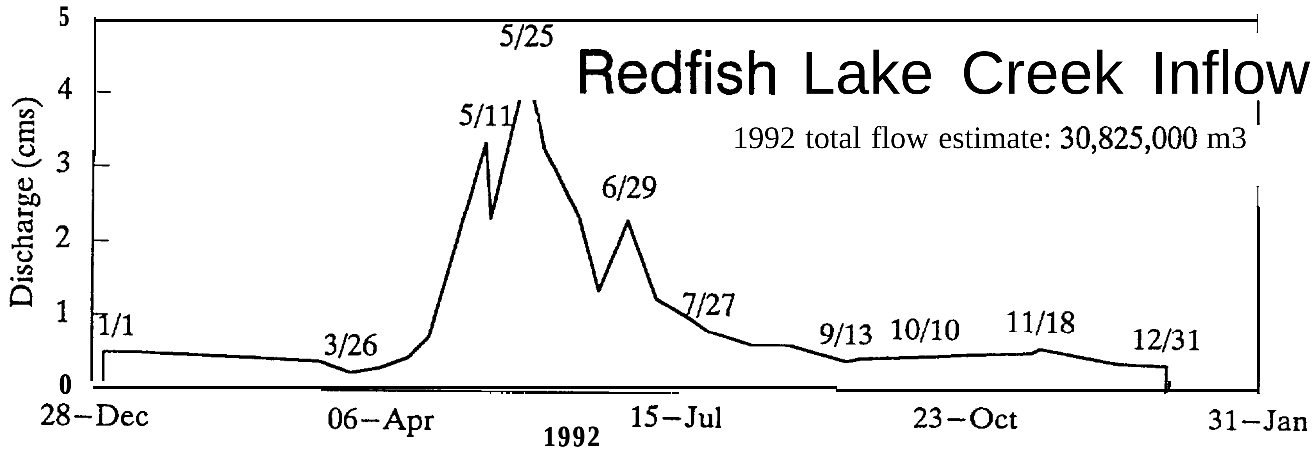


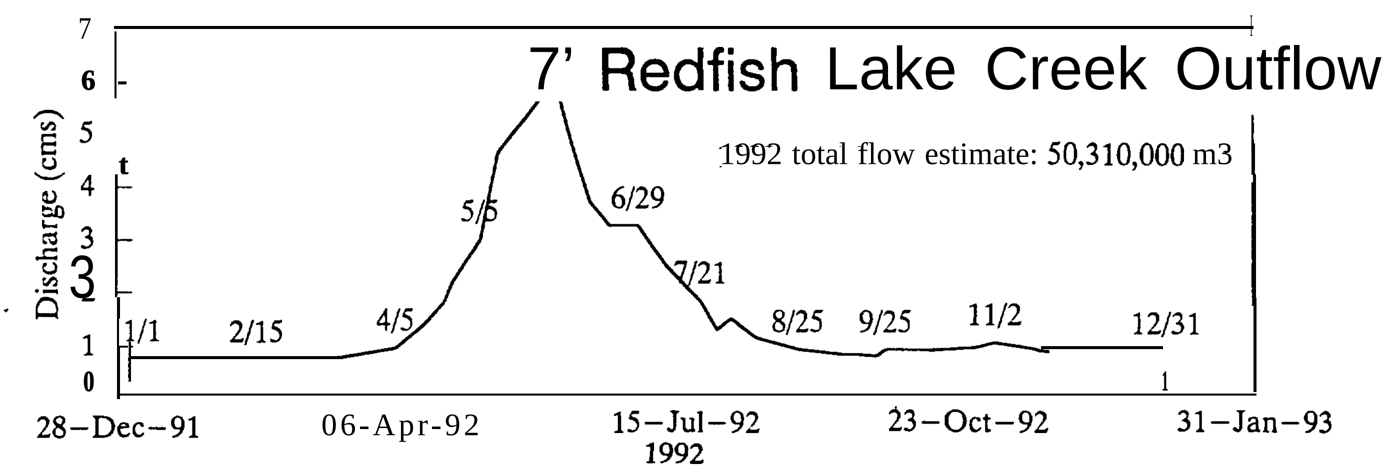


Hydrographs

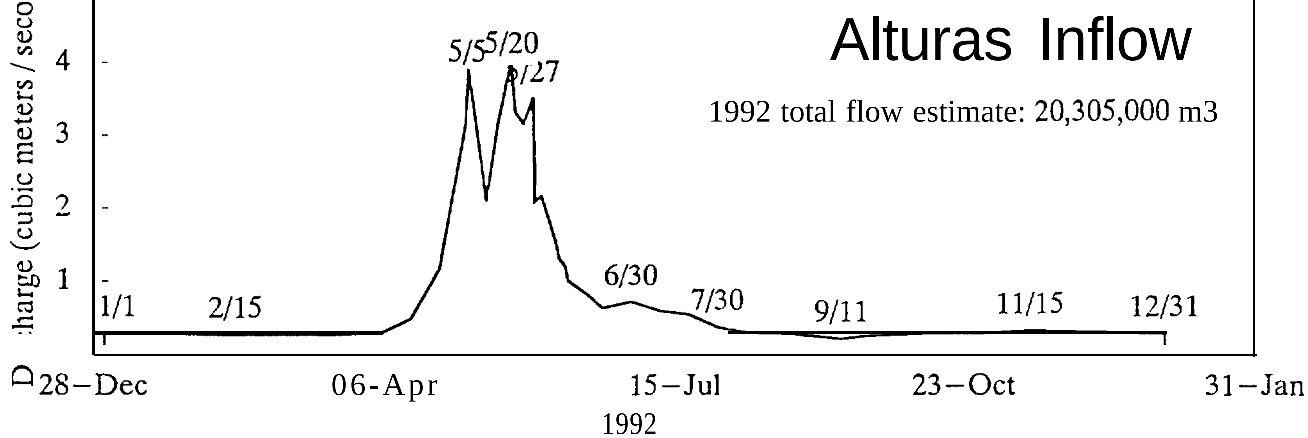


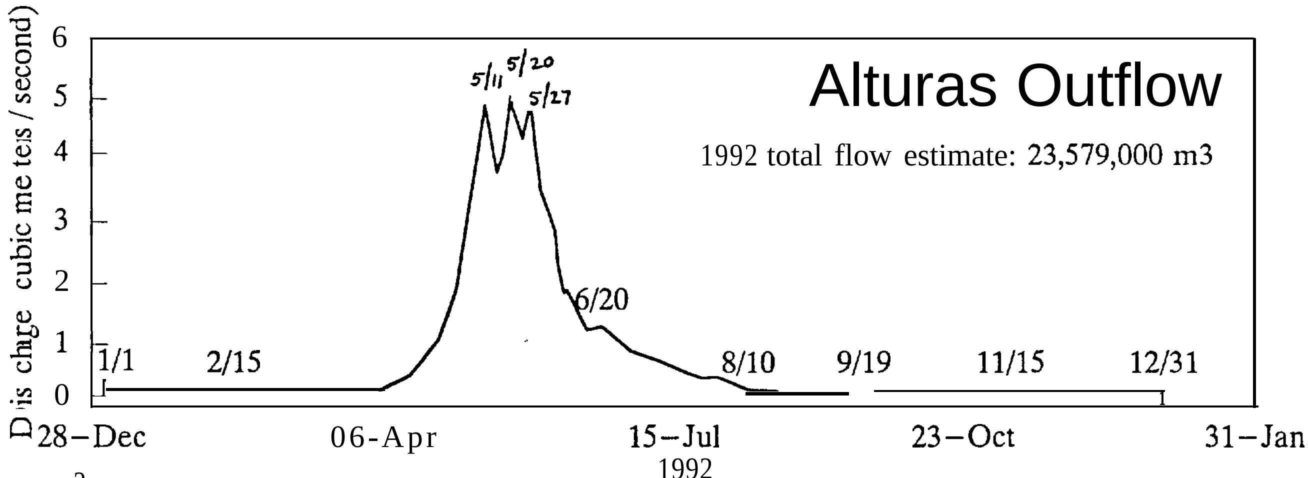


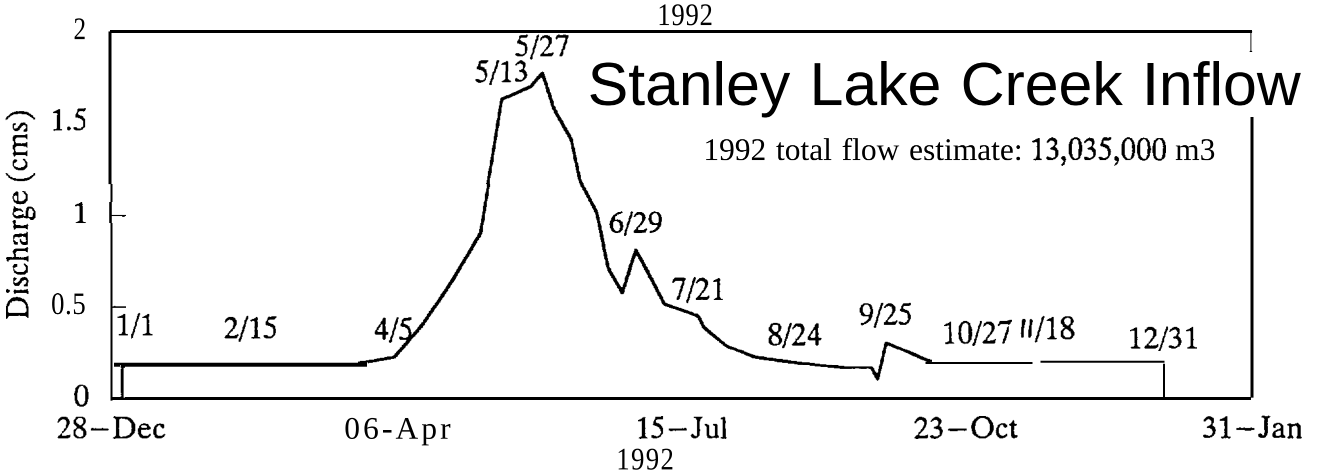


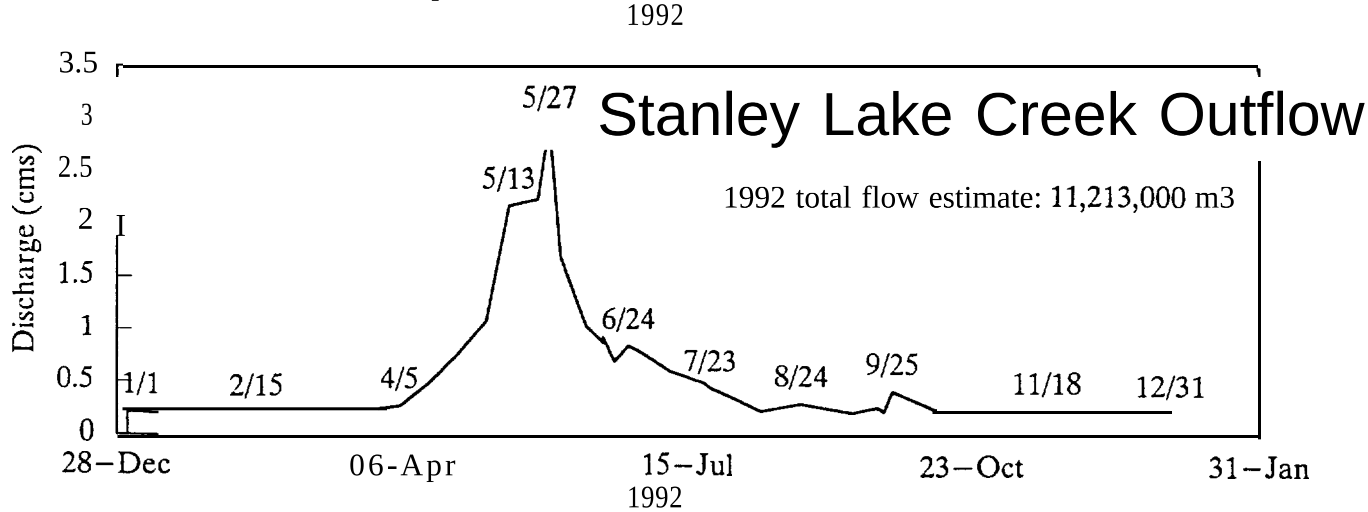


Hydrographs

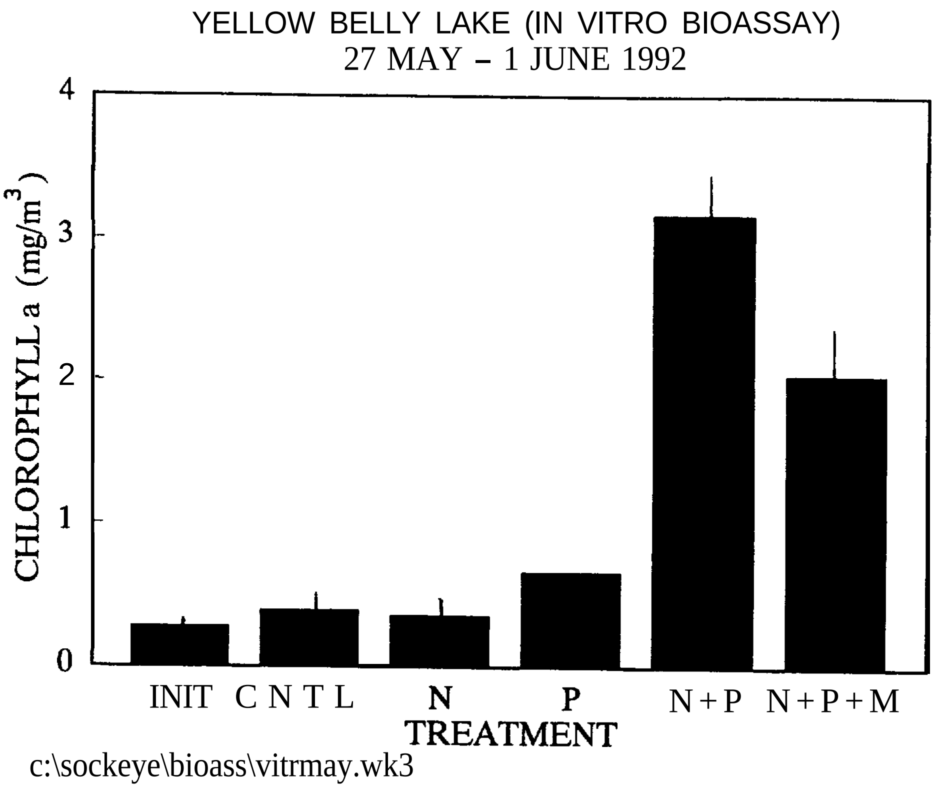








Appendix 6. Yellow Belly Lake In Vitro Bioassay



Effects of additions of nitrogen (N), phosphorus (P), nitrogen + phosphorus (N+P), and nitrogen + phosphorus + minor and micronutrients (N+P+M) on chlorophyll ***a*** production in Redfish Lake water during ***in vitro*** experiments. Chlorophyll levels in the initial water samples (INIT) and in the control (CNTL) treatments are also shown. N=2. Error bars show +1 SE of the mean.